MAGILL'S CHOICE

Geography Basics

GEOGRAPHY BASICS

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GEOGRAPHY BASICS

Volume 1

Edited by
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Publisher's Note

Geography Basics covers the most fundamental concepts of both physical and social geography that are taught in beginning high school courses on geography. However, the set is also accessible to both middle school and undergraduate college students. In order to further the geographic literacy of contemporary students, the articles in *Geography Basics* take an integrated approach to the field, emphasizing interconnections of every kind.

North Americans have long thought of the field of geography as little more than the study of the names and locations of places. This notion is not without a basis in fact: Through much of the twentieth century, geography courses emphasized memorization of names of states, capitals, rivers, seas, mountains, and countries. Both students and educators eventually rebelled against that approach, geography courses gradually fell out of favor, and the future of geography as a discipline looked doubtful. Happily, however, the field underwent a remarkable transformation during the 1990's, as Dr. Ray Sumner explains in her introduction to this set, and geography now has a bright future at all levels of education.

While learning the locations of places remains an important part of geography studies, educators recognize that place-name recognition is merely the beginning of geographic understanding. Geography now places much greater emphasis on understanding the characteristics of, and interconnections among, places. Modern students address such questions as how the weather in a remote part of the world can affect the price of a commodity in the United States, how global warming threatens small island nations, how preserving endangered animal species can conflict with the economic development of poor nations, and why other parts of the world can never be the same as North America.

The first volume of *Geography Basics* introduces the field of geography and examines basic concepts and issues. Its 59 essays are arranged under six broad headings:

- **The Nature of Geography:** 4 essays on "The History of Geography," "Mapmaking in History," " Mapmaking and New Technologies," and "Themes and Standards in Geography Education"
- **Physical Geography:** 18 essays arranged under four headings: "The Earth in Space," "Earth's Interior," "Earth's Surface," and "Earth's Climates"
- **Biogeography and Natural Resources:** 10 essays arranged under two headings: "Earth's Biological Systems" and "Natural Resources"
- **Human Geography:** 12 essays under three headings: "Human Society and the Earth," "Climate and Human Societies," and "Exploration and Transportation"

- **Economic Geography:** 11 essays under three headings: "Agriculture," "Energy and Engineering," and "Industry and Trade"
- **Political Geography:** 4 essays on "Forms of Government," "Political Geography," "Geopolitics," and "International Boundaries"

The bulk of the second volume of *Geography Basics* is devoted to a glossary of basic geographical terminology containing 1,600 definitions, plus cross-reference entries. Volume 2 also contains a comprehensive annotated bibliography and a selection of appendices summarizing global geographical data. The appendices include rankings of the world's rivers, lakes, oceans, deserts, landmasses, islands, and countries by size, as well as lists of the world's most populous cities and countries and most and least densely populated countries.

Geography Basics contains more than 30 maps and more than 250 photographs, as well as other graphical elements. In addition, the essays are punctuated with textual sidebars and tables, which amplify the information in the essays and call attention to especially important or interesting points. Every essay contains a list of recommended sources for further study, and many articles contain sidebars on relevant Web sites.

Both English and metric measures are used in this set. In most instances, English measures are given first, followed by their metric equivalents in parentheses. It should be noted that in cases of measures that are only estimates, such as areas of deserts or average heights of mountain ranges, the metric figures are often rounded off to estimates that may not be exact equivalents of the English-measure estimates. In order to enhance clarity, units of measure are not abbreviated in the text, with these exceptions: *Kilometers* are rendered as *km.* and *square kilometers* as *sq. km.* These exceptions have been made because of the frequency with which these measures appear.

Most of the material in *Geography Basics* originally appeared in Salem Press's eight-volume *World Geography* (2001). However, texts, bibliographical citations, and statistical data have all been updated. All essays were prepared by qualified academicians and experts, without whose invaluable contributions these volumes would not be possible. Their names and affiliations follow. We are especially pleased to express our thanks to Dr. Ray Sumner, of California's Long Beach City College, for the expertise and insights that she has brought to both this project and *World Geography* as Editor.

Introduction

When Henry Morton Stanley of the *New York Herald* shook David Livingstone's hand on the shore of Central Africa's Lake Tanganyika in 1871, the moment represented the high point of geography to many people throughout the world. A Scottish missionary and explorer, Livingstone had been out of contact with the outside world for nearly two years, and European and American newspapers had buzzed with speculation about his disappearance. At that time, so little was known about the geography of the interior of Africa that Stanley's finding Livingstone was acclaimed as a brilliant triumph of exploration.

The field of geography in Stanley and Livingstone's time was—and to a large extent still is—synonymous with exploration. Stories of epic journeys, both historic and contemporary, continue to exert a powerful attraction on readers. Mountains, deserts, forests, caves, and glaciers still draw intrepid explorers, while even more armchair travelers are thrilled by accounts and pictures of these exploits and discoveries. We all love to travel—to the beach, into the mountains, to our great national parks, and to foreign countries. In the need and desire to explore our surroundings, we are all geographers.

Numerous geographical societies welcome both professional geographers and the general public into their membership, as they promote a greater knowledge and understanding of the earth. The National Geographic Society, founded in 1888 "for the increase and diffusion of geographical knowledge," has funded more than 6,500 field expeditions and now has seven million dues-paying members. Each year the society invests more than five million dollars in expeditions and scientific field research related to environmental concerns and global geographic issues. The findings are recorded in the pages of the familiar yellow-bordered *National Geographic* magazine, which circles the globe with ten million copies in fifteen different languages, bringing readers up-to-date scientific information and memorable images of both familiar and exotic people and places. The National Geographic International television network reaches out to more than eighty million subscribers in 111 countries, broadcasting in sixteen languages.

An even older geographical association is Great Britain's Royal Geographical Society, which grew out of the Geographical Society of London, founded in 1830 with the "sole object" of promoting "that most important and entertaining branch of knowledge—geography." Over the century that followed, the Royal Geographical Society focused on exploration of the continents of Africa and Antarctica. In the society's London headquarters adjacent to the Albert Hall, visitors can still view such historic artifacts as David Livingstone's cap and chair, as well as diaries, sketches, and maps covering the great period of the British Empire and beyond. Today the society assists more than five hundred field expeditions every year.

With the aid of satellites and remote-sensing instruments we can now obtain images and data from almost anywhere on Earth. However, remote and inaccessible places still invite the intrepid to visit and explore them in person. Although the outlines of the continents have now been completed, and their interiors filled in with details of mountains, rivers, and cities, remote places still exert a fascination on modern urbanites.

The enchantment of tales about strange sights and courageous journeys has been with us since the ancient voyages of Homer's Ulysses, Marco Polo's travels to China, and the nautical expeditions of Christopher Columbus, Ferdinand Magellan, and James Cook. While those great travelers are from the remote past, the age of exploration is far from over—a fact repeatedly demonstrated by the modern Norwegian navigator Thor Heyerdahl. Moreover, new journeys of discovery are still taking place. In 1993, after dragging a sled wearily across the frigid wastes of Antarctica for more than three months, Sir Ranulph Twisleton-Wykeham-Fiennes announced that the age of exploration is not dead. Six years later, in 1999, the long-missing body of British mountain climber George Mallory was found on the slopes of Mount Everest, near whose top he had mysteriously vanished in 1924. That discovery sparked a new wave of admiration and respect for explorers of such courage and endurance.

Antarctica has long been a region of geographic challenges. How many people have been enthralled by the bravery of explorer Robert Falcon Scott and the noble sacrifice his injured colleague Lawrence Oates made in 1912, when he gave up his life in order not to slow down the rest of the expedition? The epic of Ernest Shackleton's unlucky expedition is regularly recounted to enthralled audiences. There can be no doubt that the thrills and the dangers of exploring find resonance among many modern readers.

The struggle to survive in environments hostile to human beings reminds us of the power of our planet Earth. Recent best-selling books on this theme have included Jon Krakauer's *Into Thin Air* (1998), an account of a disastrous expedition climbing Mount Everest, and Sebastian Junger's *The Perfect Storm* (1997), the story of the worst gale of the twentieth century and its effect on a fishing fleet off the East Coast of North America. *Endurance* (1998), the epic of Sir Ernest Shackleton's survival and leadership for two years on the frozen Arctic, attracts the same people who avidly read *Undaunted Courage* (1996), the story of Meriwether Lewis and William Clark's epic exploration of the Louisiana Purchase territories in the early nineteenth century. In 1997 *Seven Years in Tibet* premiered, a popular film about the Austrian Heinrich Harrer, who lived in Tibet in the mid-twentieth century. The more urban people become, the greater their desire for adventurous, remote places, at least vicariously, to raise the human spirit.

There are, of course, also scientific achievements associated with modern exploration. In November, 1999, the elevation of Mount Everest, the world's tallest peak, was raised by 7 feet (2.1 meters) to a new height of 29,035 feet (8,850 meters) above sea level; the previously accepted height had been based on surveys made during the 1950's. This new value was the result of Global Positioning System (GPS) technology enabling a more accurate measurement than had been possible with land-based earthbound surveying equipment. A team of climbers supported by the National Geographic Society and the Boston Museum of Science, was equipped with GPS equipment which enabled a fifty-minute recording of data based on satellite signals. At the same time, the expedition was able to ascertain that Mount Everest is moving northeast, atop the Indo-Australian Plate, at a rate of approximately 2.4 inches (10 centimeters) per year.

In 2000, the International Hydrographic Organization named a "new" ocean, the Southern Ocean, which encompasses all the water surrounding Antarctica up to 60 degrees south latitude. With an area of approximately 7.8 million square miles (20.3 million square kilometers), the Southern Ocean is about twice the size of the entire United States and ranks as the world's fourth largest ocean, after the Pacific, Atlantic, and Indian Oceans, but just ahead of the Arctic Ocean.

Despite the humanistic and scientific advantages of geographic knowledge, to many people today geography is a subject where one merely memorizes long lists of facts dealing with "where" questions (Where is Andorra? Where is Prince Edward Island? Where is Kalamazoo?) or "what" questions (What is the highest mountain in South America? What is the capital of Costa Rica?) This approach to the study of geography has been perpetuated by the annual National Geographic Bee, conducted in the United States each year for students in grades four through eight. Participants in the competition display an astonishing recall of facts but do not have the opportunity of showing any real geographic thought. To a geographer, such factual knowledge is simply a foundation for investigating and explaining the much more important questions dealing with "why"—"Why is the Sahara a desert?"

Geographers aim to understand why environments and societies occur where and as they do, and how they change. Geography must be seen as an integrative science; the collection of factual data and evidence, as in exploration, is the empirical foundation for deductive reasoning. This leads to the creation of a range of geographical methods, models, theories, and analytical approaches that serve to unify a very broad area of knowledge—the interaction between natural and human environments. Although geography as an academic discipline became established in nineteenth century Germany, there have always been geographers, in the sense of people curious about their world. Humans have always wanted to know about day and night, the shape of the earth, the nature of climates, differences in plants and animals, as well as what lies beyond the horizon. Today, as we hear about and actually experience the sweeping effects of globalization, we need more than ever to develop our geographical skills. Not only are we connected by economic ties to the countries of the world, but we must also appreciate the consequences of North America's high standard of living.

Political boundaries are artificial human inventions, but the natural world is one biosphere. As concern over global warming escalates, national leaders meet to seek a solution to emission of greenhouse gases. Are we connected to our environment? At a time when the rate of species extinction is a hundred times above normal, and the human population is crowding in increasing numbers into huge urban centers, we have, nevertheless, taken time each year in April to celebrate Earth Day since 1970. We need now to realize that every day is Earth Day.

Geography languished in the United States in the 1960's, as social studies was taught with a history emphasis in schools. American students became alarmingly disadvantaged in geographic knowledge, compared with most other countries. Fortunately members of the profession acted to restore geography to the curriculum. In 1984 the National Geographic Society undertook the challenge of restoring geography in the United States. The society turned to two organizations active in geographic education: the Association of American Geographers, the professional geographers' group with more than 6,500 members, mostly in higher education in the United States; and the National Council for Geographic Education, with some one thousand members. The council administers the Geographic Alliances, found in every state of the United States, with a national membership of about 120,000 schoolteachers. Together they produced the "Guidelines in Geographic Education," which introduced the Five Themes of Geography, to enhance the teaching of geography in schools. Using the themes of Location, Place, Human/Environment Interaction, Movement and Regions, teachers were able to plan and conduct lessons in which students encountered interesting real-world examples of the relevance and importance of geography. Continued research into geographic education led to the inclusion of geography in 1990 as one of the core subjects of the National Education Goals, or "Goals 2000," along with English, mathematics, science, and history.

Another milestone was the publication in 1994 of "Geography for Life," the national Geography Standards. The earlier Five Themes are subsumed under the new Six Essential Elements: The World in Spatial Terms, Places and Regions, Physical Systems, Human Systems, Environment and Society, and The Uses of Geography. Eighteen Geography Standards are included, describing what a geographically informed person knows and understands. States, schools, and individual teachers have welcomed the new prominence of geography, and enthusiastically adopted new approaches to introduce the geography standards to new learners.

The rapid spread of computer technology, especially in the field of Geographical Information Science, has also meant a new importance for spatial analysis, a traditional area of geographical expertise. No longer is geography seen as an outdated mass of useless or arcane facts; instead geography is now seen, again, to be an innovative and integrative science, which can in the twenty-first century contribute to solving complex problems associated with the reciprocal human-environmental relationship.

Geographers may no longer travel across uncharted realms, but there is still much we long to explore, to learn, and seek to understand, even if it is only as "armchair" geographers. This reference work, *Geography Basics*, will help carry readers on their own journeys of exploration.

Ray Sumner

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The Nature of Geography

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The History of Geography

The moment that early humans first looked around their world with inquiring minds was the moment that geography was born. The history of geography is the history of human effort to understand the nature of the world. Through the centuries, people have asked of geography three basic questions: What is the earth like? Where are things located? How can one explain these observations?

Geography in the Ancient World. In the Western world, the Greeks and the Romans were among the first to write about and study geography. Eratosthenes, a Greek scholar who lived in the third century B.C.E., is often called the "father of geography" and is credited with first using the word geography (from the Greek words *ge*, which means "earth," and *graphe*, which means "to describe"). The ancient Greeks had contact with many older civilizations and began to gather together information about the known world. Some, such as Hecataeus, described the multitude of places and peoples with which the Greeks had contact and wrote of the adventures of mythical characters in strange and exotic lands. However, the ancient Greek scholars went beyond just describing the world. They used their knowledge of mathematics to measure and locate. The Greek scholars also used their philosophical nature to theorize about Earth's place in the universe.

One Greek scholar who used mathematics in the study of geography was Anaximander, who lived from 610 to 547 B.C.E. Anaximander is credited with being the first person to draw a map of the world to scale, and he also invented a sundial that could be used to calculate time and direction, and to distinguish the seasons. Eratosthenes (276-196 B.C.E.) is also famous for his mathematical calculations, in particular of the circumfer-

Curiosity: The Root of Geography

The earliest human beings, as they hunted and gathered food and used primitive tools in order to survive, must have had detailed knowledge of the geography of their part of the world. The environment could be a hostile place, and knowledge of the world meant the difference between life and death. Human curiosity took them one step further. As they lived in an ancient world of ice and fire, human beings looked to the horizon for new worlds, crossing continents and spreading out to all areas of the globe. They learned not only to live as a part of their environment, but also to understand it, predict it, and change it to their needs.

ence of the earth, using observations of the Sun. Hipparchus, who lived around 140 B.C.E., used his mathematical skills to solve geographic problems and was the first person to introduce the idea of a latitude and longitude grid system to locate places.

Such early Greek philosophers as Plato and Aristotle were also concerned with geography. They discussed such issues as whether the earth was flat or spherical and if it was the center of the universe, and debated the nature of the earth as the home of humankind.

Whereas the Greeks were great thinkers and introduced many new ideas into geography, the Roman contribution was to compile and gather available knowledge. Although this did not add much that was new to geography, it meant that the knowledge of the ancient world was available as a base to work from and was passed down across the centuries. Geography in the ancient world is often said to have ended with the great work of Ptolemy (Claudius Ptolemaus), who lived from 90 to 168 C.E. Ptolemy is best known for his eight-volume *Guide to Geography*, which included a gazetteer of places located by latitude and longitude, and his world map.

The study of geography also was important in ancient China. Chinese scholars described their resources, climate, transportation routes, and travels, and were mapping their known world at the same time as were the great Western civilizations.

Geography in the Middle Ages. With the collapse of the Roman Empire in the fifth century C.E., Europe descended into what is commonly known as the Dark or Middle Ages. During this time, which lasted until the fifteenth century, the geographic knowledge of the ancient world was either lost or challenged as being counter to Christian teachings. For example, the early Greeks had theorized that the earth was a sphere, but this was rejected during the Middle Ages. Scholars of the Middle Ages believed that the world was said to be a flat disk, with the holy city of Jerusalem at its center.

The knowledge and ideas of the ancient world might have been lost if they had not been preserved by Muslim scholars. In the Islamic countries of North Africa and the Middle East, some of the scholarship of the ancient world was sheltered in libraries and universities. This knowledge was extensively added to as Muslims traveled and traded across the known world, gathering their own information.

Among the most famous Muslim geographers were Ibn Battutah, al-Idrisi, and Ibn Khaldun. Ibn Battutah traveled east to India and China in the fourteenth century. Al-Idrisi (1100-1165), at the command of King Roger II of Sicily, wrote *Roger's Book*, which systematically described the world. Information from *Roger's Book* was engraved on a huge planisphere (disk), crafted in silver; this once was considered a wonder of the world, but it is thought to have been destroyed. Ibn Khaldun (1332-1406) is best known for his written world history, but he also was a pioneer in focusing on the relationship of human beings to their environment.

The Age of European Exploration. Beginning in the fifteenth century, the isolation of Europe came to an end, and Europeans turned their attention to exploration. The two major goals of this sudden surge in exploration were to spread the Christian faith and to obtain needed resources. In 1418 Prince Henry the Navigator established a school for navigators and began to gather the tools and knowledge needed for exploration. He was the first of many Europeans who broke out of the darkness of the Middle Ages, traveling beyond the limits of the known world, mapping, describing, and cataloging all that they saw.

The great wave of European exploration brought new interest in geography, and the monumental works of the Greeks and Romans—so carefully preserved by Muslim scholars—were rediscovered and translated into Latin. The maps produced in the Middle Ages were of little use to the explorers who were traveling to, and beyond, the limits of the known world. Christopher Columbus, for example, relied on Ptolemy's work during his voyages to the Americas, but soon newer, more accurate maps were drawn and, for the first time, globes were made. A particularly famous map, which is still used as a base map, is the Mercator projection. On the world map produced by Gerardus Mercator (Gerhard Kremer) in 1569, compass directions appear as straight lines, which was a great benefit on navigational charts.

When the age of European exploration began, the best world maps crudely depicted a few limited areas of the world. Explorers quickly began to gather huge quantities of information, making detailed charts of coastlines, discovering new continents, and eventually filling in the maps of those continents with information about both the natural and human features they encountered. This age of exploration is often said to have ended when Roald Amundsen planted the Norwegian flag at the South Pole in 1911. At that time, the world map became complete, and human beings had mapped and explored every corner of the globe. However, the beginning of modern geography is usually associated with the work of two nineteenth century German geographers: Alexander von Humboldt and Carl Ritter.

The Beginning of Modern Geography. The writings of Alexander von Humboldt and Karl Ritter mark a leap into modern geography, because these writers took an important step beyond the work of previous scholars. The explorers of the previous centuries had focused on gathering information, describing the world, and filling in the world map with as much detail as possible. Humboldt and Ritter took a more scientific and systematic approach to geography. They began not only to compile descriptive information, but also to ask why: Humboldt spent his lifetime looking for relationships among such things as climate and topography (landscape), while Ritter was intrigued by the multitude of connections and relationships he observed within human geographic patterns. Both Humboldt and Ritter died in 1859, ending a period when information-gathering had been paramount. They brought geography into a new age in which synthesis, analysis, and theory-building became central.

European Geography. After the work of Humboldt and Ritter, geography became an accepted academic discipline in Europe, particularly in Germany, France, and Great Britain. Each of these countries emphasized different aspects of geographic study. German geographers continued the tradition of the scientific view, using observable data to answer geographic questions. They also introduced the concept that geography could take a chorological view, studying all aspects, physical and human, of a region and of the interrelationships involved.

The chorological view came to dominate French geography. Paul Vidal de la Blache (1845-1918) was the most prominent French geographer. He advocated the study of small, distinct areas, and French geographers set about identifying the many regions of France. They described and analyzed the unique physical and human geographic complex that was to be found in each region. An important concept that emerged from French geography was "possibilism." German geographers had introduced the notion of environmental determinism—that human beings were largely shaped and controlled by their environments. Possibilism rejected the concept of environmental determinism, asserting that the relationship between human beings and the environment works in two directions: The environment creates both limits and opportunities for people, but people can react in different ways to a given environment, so they are not controlled by it.

British geographers, influenced by the French approach, conducted regional surveys. British regional studies were unique in their emphasis on planning and geography as an applied science. From this work came the concept of a functional region—an area that works together as a unit based on interaction and interdependence.

American Geography. Prior to World War II, only a small group of people in the United States called themselves geographers. They were mostly influenced by German ideas, but the nature of geography was hotly debated. Two schools of geographers were philosophical adversaries. The Midwestern School, led by Richard Hartshorne, believed that description of unique regions was the central task of geography.

The Western (or Berkeley) School of geography, led by Carl Sauer, agreed that regional study was important, but believed it was crucial to go beyond description. Sauer and his followers included genesis and process as important elements in any study. To understand a region and to know where it is going, they argued, one must look at its past and how it got to its present state.

In the 1930's, environmental determinism was introduced to U.S. geography but ultimately was rejected. Although geography in both Europe and the United States was essentially an all-male discipline, the United States produced the first famous woman geographer, Ellen Churchill Semple (1863-1932).

The National Geographic Society and Geographic Research

In 1888 the National Geographic Society was founded to support the "increase and diffusion of geographic knowledge" of the world. In its first 110 years, the society funded more than five thousand expeditions and research projects with more than sixty-five hundred grants. By the 1990's it was the largest such foundation in the world, and the results of its funded projects are found on television programs, video discs, video cassettes, and books, as well as in the *National Geographic* magazine, established in 1888. Its productions are cutting-edge resources for information about archaeology, ethnology, biology, and both cultural and physical geography.

World War II illustrated the importance of geographic knowledge, and after the war came to an end in 1945, geographers began to blossom in the United States. From the end of World War II to the early 1960's, U.S. geographers produced many descriptive regional studies.

In the early 1960's, what is often called the quantitative revolution occurred. The development of computers allowed complex mathematical analysis to be performed on all kinds of geographic data, and geographers began to analyze a wide range of problems using statistics. There was great enthusiasm for this new approach to geography at first, but beginning in the 1970's, many people considered a purely mathematical approach to be somewhat sterile and thought it left out a valuable human element.

In the 1980's and 1990's, many new ways to look at geographic issues and problems were developed, including humanism, behaviorism, Marxism, feminism, realism, structuration, phenomenology, and postmodernism, all of which bring human beings back into focus within geographical studies.

Geography for a New Millennium. Geography increasingly uses technology to analyze global space and answer a wide range of questions. The Geographic Information System (GIS), in particular, provides a powerful way for people trained in geography to understand geographic issues, solve geographic problems, and display geographic information. Geographers continue to adopt a wide variety of philosophies, approaches, and methods in their quest to answer questions concerning all things spatial.

Wendy Shaw

For Further Study

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Information on the World Wide Web

A good starting point for Internet research on the history of geography is the About.com geography site, which contains links to pages on physical, regional, and human geography.
(geography.about.com/education/geography/).

The Web site of the Environmental Systems Research Institute, an early leader in mapping products using GIS technology, allows viewers to create maps using GIS data and download ArcExplorer, a free GIS data viewer (www.esri.com/software/arcexplorer/index.html).

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Mapmaking in History

Cartography is the science or art of making maps. Although workers in many fields have a concern with cartography and its history, it is most often associated with geography.

Maps of Preliterate Peoples. The history of cartography predates the written record, and most cultures show evidence of mapping skills. The earliest surviving maps are those carved in stone or painted on the walls of caves, but modern preliterate peoples still use a variety of materials to express themselves cartographically. For example, the Marshall Islanders use palm fronds, fiber from coconut husks (coir), and shells to make sea charts for their inter-island navigation. The Inuit use animal skins and driftwood, sometimes painted, in mapping. There is a growing interest in the cartography of early and preliterate peoples, but some of their maps do not fit readily into a more traditional concept of cartography.

Mapping in Antiquity. Early literate peoples, such as those of Egypt and Mesopotamia, displayed considerable variety in their maps and charts, as shown by the few maps from these civilizations that still exist. The early Egyptians painted maps on wooden coffin bases to assist the departed in finding their way in the afterlife; they also made practical route maps for their mining operations. It is thought that geometry developed from the

This map of the world was published in 1607, when European geographers had only the vaguest ideas of what lay west of the Americas, and the great southern continent, "Terra Australis," existed only in theory. (Corbis)

Egyptians' riverine surveys. The Babylonians made maps of different scales, using clay tablets with cuneiform characters and stylized symbols, to create city plans, regional maps, and "world" maps. They also divided the circle in the sexigesimal system, an idea they may have obtained from India and that is commonly used in cartography to this day.

The Greeks inherited ideas from both the Egyptians and the Mesopotamians and made signal contributions to cartography themselves. No direct evidence of early Greek maps exists, but indirect evidence in texts provides information about their cosmological ideas, culminating in the concept of a perfectly spherical earth. This they attempted to measure and divide mathematically. The idea of climatic zones was proposed and possibly mapped, and the large known landmasses were divided into first two continents, then three.

Perhaps the greatest accomplishment of the early Greeks was the remarkably accurate measurement of the circumference of the earth by Eratosthenes. Serious study of map projections began at about this time. The gnomonic, orthographic, and stereographic projections were invented before the Christian era, but their use was confined to astronomy in this period. With the possible single exception of Aristarchus of Samos, the Greeks believed in a geocentric universe. They made globes (now lost) and regional maps on metal; a few map coins from this era have survived.

Later Greeks carried on these traditions and expanded upon them. Claudius Ptolemy invented two projections for his world maps in the second century C.E. These were enormously important in the European Renaissance as they were modified in the light of new overseas discoveries. Ptolemy's work is known mainly through later translations and reconstructions, but he compiled maps from Greek and Phoenician travel accounts and proposed sectional maps of different scales in his *Geographia*. Ptolemy's prime meridian (0 degrees longitude) in the Canary Islands was generally accepted for a millennium and a half after his death.

Roman cartography was greatly influenced by later Greeks such as Ptolemy, but the Romans themselves improved upon route mapping and surveying. Much of the Roman Empire was subdivided by instruments into hundredths, of which there is a cartographic record in the form of marble tablets. In Rome, a small-scale map of the world known to the Romans was made on metal by Marcus Vipsanius Agrippa, the son-in-law of Augustus Caesar, and displayed publicly. This map no longer exists, however.

Cartography in Early East Asia. As these developments were taking place in the West, a rich cartographic tradition developed in Asia, particularly China. The earliest survey of China (Yu Kung) is approximately contemporaneous with the oldest reported mapmaking activity of the Greeks. Later, maps, charts, and plans accompanied Chinese texts on various geographical themes. Early rulers of China had a high regard for cartography—the science of princes. A rectangular grid was introduced by

Chang Heng, a contemporary of Ptolemy, and the south-pointing needle was used for mapmaking in China from an early date.

These traditions culminated in Chinese cartographic primacy in several areas: the earliest printed maps (about 1155 C.E.), early printed atlases, and terrestrial globes (now lost). Chinese cartography greatly influenced that in other parts of Asia, particularly Korea and Japan, which fostered innovations of their own. It was only after the introduction of ideas from the West, in the Renaissance and later, that Asian cartographic advances were superseded.

Islamic Cartography. A link between China and the West was provided by the Arabs, particularly after the establishment of Islam. It was probably the Arabs who brought the magnetized needle to the Mediterranean, where it was developed into the magnetic compass.

Some scholars have argued that the Arabs were better astronomers than cartographers, but did make several clear advances in mapmaking. Both fields of study were important in Muslim science, and the astrolabe, invented by the Greeks in antiquity but developed by the Arabs, was used in both their astronomical and terrestrial surveys. They made and used many maps, as indicated by the output of their most famous cartographer, al-Idrisi (who lived about 1100-1165). Some of his work still exists, including a zonal world map and detailed charts of the Mediterranean islands.

At about the same time, the magnetic compass was invented in the coastal cities of Italy, which gave rise to advanced navigational charts, including information on ports. These remarkably accurate charts were used for navigating in the Mediterranean Sea. They were superior to the European maps of the Middle Ages, which often were concerned with religious iconography, pilgrimage, and crusade. The scene was now set for the great overseas discoveries of the Europeans, which were initiated in Portugal and Spain in the fifteenth century.

In the next four centuries, most of the coasts of the world were visited and mapped. The early, projectionless navigational charts were no longer adequate, so new projections were invented to map the enlarged world as revealed by the European overseas explorations. The culmination of this activity was the development of the projection, in 1569, of Gerardus Mercator, which bears his name and is of special value in navigation.

Early Modern Mapmaking. Europeans began mapping their own countries with greater accuracy. New surveying instruments were invented for this purpose, and a great land-mapping activity was undertaken to match the worldwide coastal surveys. For about a century, the Low Countries of Belgium, Luxembourg, and the Netherlands dominated the map and chart trades, producing beautiful hand-colored engraved sheet wall maps and atlases.

France and England established new national observatories, and by the middle of the seventeenth century, the Low Countries had been eclipsed by France in surveying and making maps and charts. The French adopted the method of triangulation of Mercator's teacher, Gemma Friisius. Under four generations of the Cassini family, a topographic survey of France more comprehensive than any previous survey was completed. Rigorous coastal surveys were undertaken, as well as the precise measurement of latitude (parallels).

The invention of the marine chronometer by John Harrison made it possible for ships at sea to determine longitude. This led to the production of charts of all the oceans, with England's Greenwich eventually being adopted as the international prime meridian.

Quantitative, thematic mapping was advanced by astronomer Edmond Halley (1656-1742) who produced a map of the trade winds; the first published magnetic variation chart, using isolines; tidal charts; and the earliest map of an eclipse. The Venetian Vincenzo Coronelli made globes of greater beauty and accuracy than any previous ones. In the German lands, the study of map projections was vigorously pursued. Johann H. Lambert and others invented a number of equal-area projections that were still in use in the twentieth century.

Ideas developed in Europe were transmitted to colonial areas, and to countries such as China and Russia, where they were grafted onto existing cartographic traditions and methods. The oceanographic explorations of the British and the French built on the earlier charting of the Pacific Ocean and its islands by native navigators and the Iberians.

Nineteenth Century Cartography. Cartography was greatly diversified and developed in the nineteenth century. Quantitative, thematic mapping was expanded to include the social as well as the physical sciences. Alexander von Humboldt used isolines to show mean air temperature, a method that later was applied to other phenomena. Contour lines gradually replaced less quantitative methods of representing terrain on topographic maps. Such maps were made of many areas, for example India, which previously had been poorly mapped.

Extraterrestrial (especially lunar) mapping, had begun seriously in the preceding two centuries with the invention of the telescope. It was expanded in the nineteenth century. In the same period, regular national censuses provided a large body of data that could be mapped. Ingenious methods were created to express the distribution of population, diseases, social problems, and other data quantitatively, using uniform symbols.

Geological mapping began in the nineteenth century with the work of William Smith in England, but soon was adopted worldwide and systematized, notably in the United States. The same is true of transportation maps, as the steamship and the railroad increased mobility for many people. Faster land travel in an east-west direction, as in the United States, led to the official adoption of Greenwich as the international prime meridian at a conference held in Washington, D.C., in 1884. Time zone maps were soon published and became a feature of the many world atlases then being published for use in schools, offices, and homes.

A remarkable development in cartography in the nineteenth century was the surveying of areas newly occupied by Europeans. This occurred in such places as the South American republics, Australia, and Canada, but was most evident in the United States. The U.S. Public Land Survey covered all areas not previously subdivided for settlement. Property maps arising from surveys were widely available, and in many cases, the information was contained in county and township atlases and maps.

Modern Mapping and Imaging. Cartography was revolutionized in the twentieth century by aerial photography, sonic sounding, satellite imaging, and the computer. Before those developments, however, Albrecht Penck proposed an ambitious undertaking—an International Map of the World (IMW). Cartography historically had been a nationalistic enterprise, but Penck suggested a map of the world in multiple sheets produced cooperatively by all nations at the scale of 1:1,000,000 with uniform symbols. This was started in the first half of the twentieth century but was not completed, and was superseded by the World Aeronautical Chart (WAC) project, at the same scale, during and after World War II.

The WAC project owed its existence to flight information made available following the invention of the airplane. Both photography and balloons were developed before the twentieth century, but the new, heavier-than-air craft permitted overlapping aerial photographs to be taken, which greatly facilitated the mapping process. Aerial photography revolutionized land surveys—maps could be made at less cost, in less time, and with greater accuracy than by previous methods. Similarly, marine surveying was revolutionized by the advent of sonic sounding in the second half of the twentieth century. This enabled mapping of the floor of the oceans, essentially unknown before this time.

Satellite imaging, especially continuous surveillance by Landsat since 1972, allows temporal monitoring of the earth. The computer, through Geographical Information Systems (GIS) and other technologies, has greatly simplified and speeded up the mapping process. During the twentieth century, the most widely available cartographic product was the road map for travel by automobile.

Spatial information now comes through television and computer screens as well as by more traditional cartographic means. The new media also facilitate animated presentations of geographical and extraterrestrial distributions. Cartographers in the twentieth century generally have been responsive to the opportunities provided by new technologies, materials, and ideas.

Norman J. W. Thrower

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Mapmaking and New Technologies

The field of geography is concerned primarily with the study of the curved surface of the earth. The earth is huge, however, with an equatorial radius of 3,963 miles (6,378 km.). How can one examine anything more than the small patch of earth that can be experienced at one time? Geographers do what scientists do all of the time: create models. The most common model of the earth is a globe—a spherical map that is usually about the size of a basketball.

A globe can show physical features such as rivers, oceans, the continents, and even the ocean floor. Political globes show the division of the earth into countries and states. Globes can even present views of the distant past of the earth, when the continents and oceans were very different than they are today. Globes are excellent for learning about the distributions, shapes, sizes, and relationships of features of the earth. However, there are limits to the use of globes.

How can the distribution of people over the entire world be described at one glance? On a globe, the human eye can see only half of the earth at one time. What if a city planner needs to map every street, building, fire hydrant, and streetlight in a town? To fit this much detail on a globe, the globe might have to be bigger than the town being mapped. Globes like these would be impossible to create and to carry around. Instead of having to hire a fleet of flatbed trucks to haul oversized globes, the curved surface of the globe can be transformed to a flat plane.

The method used to change from a curved globe surface to a flat map surface is called a map projection. There are hundreds of projections, from simple to extremely complex and dating from about two thousand years ago to projections being invented today. One of the oldest is the gnomonic projection. Imagine a clear globe with a light inside. Now imagine holding a piece of paper against the surface of the globe. The coastlines and parallels of latitude and meridians of longitude would show through the globe and be visible on the paper. Computers can do the same thing because there are mathematical formulas for nearly all map projections.

Geometric Models for Map Projections. One way to organize map projections is to imagine what kind of geometric shape might be used to create a map. Like the paper (a plane surface) against the globe described above, other useful geometric shapes include a cone and a cylinder. When the rounded surface of any object, including the earth, is flattened there must be some stretching, or tearing. Map projections help to control the amount and kinds of distortion in maps. There are always a few exceptions that cannot be described in this way, but using geometric shapes helps to classify projections into groups and to organize the hundreds of projections.

Another way to describe a map projection is to consider what it might be good for. Some map projections show all of the continents and oceans at their proper sizes relative to one another. Another type of projection can show correct distances between certain points.

Map Projection Properties. When areas are retained in the proper size relationships to one another, the map is called an equal-area map, and the map projection is called an equal-area projection. Equal-area (also called equivalent or homolographic) maps are used to measure areas or view densities such as a population density.

If true angles are retained, the shapes of islands, continents, and oceans look more correct. Maps made in this way are called conformal maps or conformal map projections. They are used for navigation, topographic mapping, or in other cases when it is important to view features with a good representation of shape. It is impossible for a map to be both equal-area and conformal at the same time. One or the other must be selected based on the needs of the map user or map maker.

One special property—distance—can only be true on a few parts of a map at one time. To see how far it is between places hundreds or thousands of miles apart, an equidistant projection should be used. There will be several lines along which distance is true. The azimuthal equidistant projection shows true distances from the center of the map outward. Some map projections do not retain any of these properties but are useful for showing compromise views of the world.

Modern Mapmaking. Modern mapmaking is assisted from beginning to end by digital technologies. In the past, the paper map was both the primary means for communicating information about the world and the database used to store information. At the start of the twenty-first century, the database is a digital database stored in computers, and cartographic visualizations have taken the place of the paper map. Visualizations may still take the form of paper maps, but they also can appear as flashes on computer screens, animations on local television news programs, and even on screens within vehicles to help drivers navigate. Communication of information is one of the primary purposes of making maps. Mapping helps people to explore and analyze the world.

Making maps has become much easier and the capability available to many people. Desktop mapping software and Internet mapping sites can make anyone with a computer an instant cartographer. The maps, or cartographic visualizations, might be quite basic but they are easy to make. The procedures that trained cartographers use to make map products vary in the choice of data, software, and hardware, but several basic design steps should always take place.

First, the purpose and audience for whom the map is being made must be clear. Is this to be a general reference map or a thematic map? What image should be created in the mind of the map reader? Who will use the map? Will it be used to teach young children the shapes of the continents and oceans, or to show scientists the results of advanced research? What form will the cartographic visualization take? Will it be a paper map, a graphic file posted to the Internet, or a video?

The answers to these questions will guide the cartographer in the design process. The design process can be broken down into stages. In the first stage of map design, imagination rules. What map type, size and shape, basic layout, and data will be used? The second stage is more practical and consists of making a specific plan. Based on the decisions made in the first stage, the symbols, line weights, colors, and text for the map are chosen. By the end of this stage, there should be a fairly clear plan for the map. During the third stage, details and specifications are finalized to account for the production method to be used. The actual software, hardware, and methods to be used must all be taken into consideration.

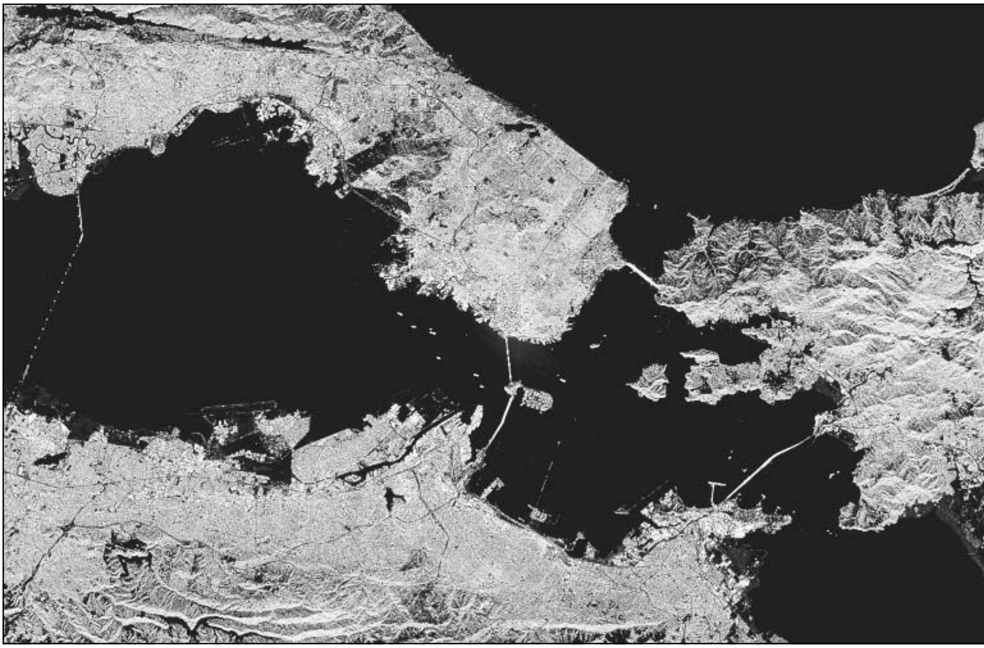
What makes a good map? Working in the modern digital environment, the mapmaker can change and test various designs easily. The map is a good one when it communicates the intended information, is pleasing to look at, and encourages map readers to ask thoughtful questions.

New Technologies. Mapping technology has gone from manual to magnetic, then to mechanical, optical, photochemical, and electronic

Sliding Rocks Get Digital Treatment

Dr. Paula Messina studied the trails of rocks that slide across the surface of a flat playa in Death Valley, California. The sliding rocks have been studied in the past, but no one had been able to say for certain how or when the rocks moved. It was unclear whether the rocks were caught in ice floats during the winter, were blown by strong winds coming through the nearby mountains, or were moved by some other method.

Messina gave the mystery a totally digital treatment. She mapped the locations of the rocks and the rock trails using the global positioning system (GPS) and entered her rock trail data into a geographic information system (GIS) for analysis. She was able to determine that ice was not the moving agent by studying the pattern of the trails. She also used digital elevation models (DEM) and remotely sensed imagery to model the environment of the playa. She reported her results in the form of maps using GIS's cartographic output capabilities. While she did not solve completely the mystery of the sliding rocks, she was able to disprove that winter ice caused the rocks to slide along together in rafts and that there are wind gusts strong enough to move the biggest rock on the playa.



Features in this infrared satellite image of San Francisco Bay make the photograph almost as easy to read as a map. San Francisco (at the top) is linked to Marin County (right) by Golden Gate Bridge. The picture was taken from the space shuttle Discovery *in 1991.* (PhotoDisc)

methods. All of these methods have overlapped one another and each may still be used in some map-making processes. There have been recent advances in magnetic, optical, and most of all, electronic technologies.

All components of mapping systems—data collection, hardware, software, data storage, analysis, and graphical output tools—have been changing rapidly. Collecting location data, like mapping in general, has been more accessible to more people. The development of the Global Positioning System (GPS), an array of satellites orbiting the earth, gives anyone with a GPS receiver access to location information, day or night, anywhere in the world. GPS receivers are also found in planes, passenger cars, and even in the backpacks of hikers.

Satellites also have helped people to collect data about the world from space. Orbiting satellites collect images using visible light, infrared energy, and other parts of the electromagnetic spectrum. Active sensing systems send out radar signals and create images based on the return of the signal. The entire world can be seen easily with weather satellites, and other specialized satellite imagery can be used to count the trees in a yard.

These great resources of data are all stored and maintained as binary, computer-readable information. Developments in laser technology provide large amounts of storage space on media such as optical disks and compact disks. Advances in magnetic technology also provide massive storage capability in the form of tape storage, hard drives, and floppy drives. This is especially important for saving the large databases used for mapping.

Computer hardware and software continue to become more powerful and less expensive. At home or school, personal computers in the year 2000 were more powerful than the mainframe computers at research universities had been ten years earlier. Software continues to be developed to serve the specialized needs that mapping requires. Just as word processing software can format a paper, check spelling and grammar, draw pictures and shapes, import tables and graphics, and perform dozens of other functions, specialized software executes maps. The most common software used for mapping is called Geographic Information System software. These systems provide tools for data input and for analysis and modeling of real-world spatial data, and provide cartographic tools for designing and producing maps.

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Information on the World Wide Web

In addition to using map projections to make whole maps, one can also divide up, or tessellate, the surface of the earth into various geometric shapes. The Web site of the National Geographic Data Center at the National Oceanic and Atmospheric Administration (NOAA) displays a Surface of the Earth Icosahedron Globe.
(www.ngdc.noaa.gov/mgg/announcements/announce_icosahedron.html)

The Modified Collignon is also called Clarke's Butterfly because of its shape when flattened. The completed form is an octahedron composed of eight triangular sides. A version of this projection can be downloaded for free from geography.hunter.cuny.edu/mp/gif/Butterfly.gif.

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Themes and Standards in Geography Education

Many people believe that the study of geography consists of little more than knowing the locations of places. Indeed, in the past, whole generations of students grew up memorizing states, capitals, rivers, seas, mountains, and countries. Most students found that approach boring and irrelevant. During the 1990's, however, geography education in the United States underwent a remarkable transformation.

While it remains important to know the locations of places, geography educators know that place name recognition is just the beginning of geographic understanding. Geography classes now place greater emphasis on understanding the characteristics of and the connections between places. Three things have led to the renewal of geography education: the five themes of geography, the national geography standards, and the establishment of a network of geographic alliances.

The Five Themes of Geography. One of the first efforts to move geography education beyond simple memorization was the National Geographic Society's publication of five themes of geography in 1984: location, place, human-environment interactions, movement, and regions. Not intended to be a checklist or recipe for understanding the world, these themes merely provided a framework for teachers—many of whom did not have a background in the subject—to incorporate geography throughout a social studies curriculum. The five themes were promoted widely by the National Geographic Society and are still used by some teachers to organize their classes.

Location is about knowing where things are. Both the absolute location (where a place is on earth's surface) and relative location (the connections between places) are important. The concept of place involves the physical and human characteristics that distinguish one place from another. The theme of human/environment interaction recognizes that people have relationships within defined places and are influenced by their surroundings. For example, many different types of housing have been created as adaptations to the world's diverse climates. The theme of movement involves the flow of people, goods, and ideas around the world. Finally, regions are human creations to help organize and understand the earth, and geography studies how they form and change.

Geography Standards

The geographically informed person knows and understands the following:

- how to use maps and other geographic representations, tools, and technologies to acquire, process, and report information from a spatial perspective;
- how to use mental maps to organize information about people, places, and environments in a spatial context;
- how to analyze the spatial organization of people, places, and environments on Earth's surface;
- the physical and human characteristics of places;
- that people create regions to interpret Earth's complexity;
- how culture and experience influence people's perceptions of places and regions;
- the physical processes that shape the patterns of Earth's surface;
- the characteristics and spatial distribution of ecosystems on Earth's surface;
- the characteristics, distribution, and migration of human populations on Earth's surface;
- the characteristics, distribution, and complexity of Earth's cultural mosaics;
- the patterns and networks of economic interdependence on Earth's surface;
- the processes, patterns, and functions of human settlement;
- how the forces of cooperation and conflict among people influence the division and control of Earth's surface;
- how human actions modify the physical environment;
- how physical systems affect human systems;
- the changes that occur in the meaning, use, distribution, and importance of resources;
- how to apply geography to interpret the past;
- how to apply geography to interpret the present and plan for the future.

The National Geography Standards. Geography was one of six subjects identified by President George H. W. Bush and the governors of the U.S. states when they formulated the National Education Goals in 1989. While the goals themselves foundered amid the political debate that followed their adoption, one tangible result of the initiative was the creation of Geography for Life: The National Geography Standards. More than one thousand teachers, professors, business people, and government officials were involved in the writing of Geography for Life. The project was supported by four geography organizations: the American Geographical Society, the Association of American Geographers, the National Council for Geographic Education, and the National Geographic Society. The resulting book defines what every U.S. student should know and be able to accomplish in geography.

Each of the eighteen standards is designed to develop students' geographic skills, including asking geographic questions; acquiring, organizing, and analyzing geographic information; and answering the questions. Each standard features explanations, examples, and specific requirements for students in grades four, eight, and twelve.

Geography Alliances and the Future of Geography Education. To publicize efforts in geography education, a network of geography alliances was established between 1986 and 1993. Each U.S. state has a geography alliance that links university professors, practicing teachers, and organizations such as the National Geographic Society and the National Council for Geographic Education. The alliances sponsor summer workshops, teacher training sessions, field experiences, and other ways of sharing the best in geographic teaching and learning.

In 2000 the future of geography education in the United States appeared to be bright. The geography alliances created a network of motivated teachers eager to share their excitement about the world. Enrollment in geography classes had risen at all levels, an advanced placement course in geography had been approved, and new learning materials guided by the national standards were being developed for students at all levels.

Eric J. Fournier

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Information on the World Wide Web

National Council for Geographic Education maintains a Web site that offers publications and activities for teachers and students. (www.ncge.org)

The National Geographic Society's Education site features sections on on-line adventures, maps and geography, lesson plans, and teacher support. (www.nationalgeographic.com/education/)

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Physical Geography

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The Earth in Space

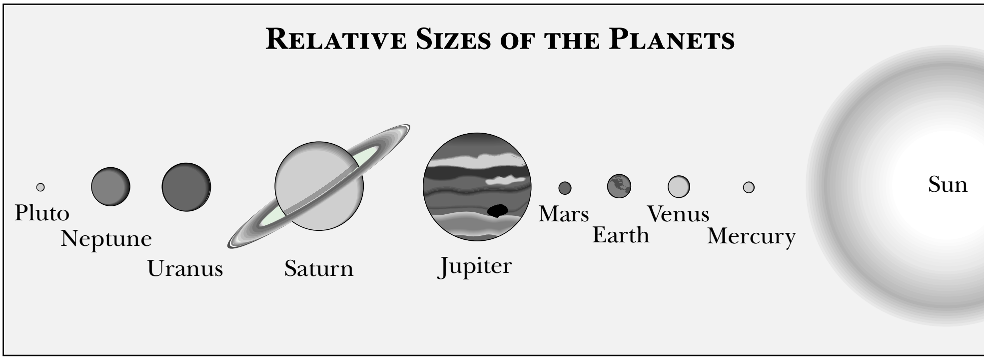
The Solar System

Earth's solar system comprises the Sun and its planets, as well as all the natural satellites, asteroids, meteors, and comets that are captive around it. The solar system formed from an interstellar cloud of dust and gas, or nebula, about 4.6 billion years ago. Gravity drew most of the dust and gas together to make the Sun, a medium-size star with an estimated life span of ten billion years. Its system is located in the Orion arm of the Milky Way galaxy, about two-thirds of the way out from the center.

During the Sun's first 100 million years, the remaining rock and ice smashed together into increasingly larger chunks, or planetesimals, until the planets, moons, asteroids, and comets reached their present state. The resulting disk-shaped solar system can be divided into four regions—terrestrial planets, giant planets, the Kuiper Belt, and the Oort Cloud—each containing its own types of bodies.

Terrestrial Planets. In the first region are the terrestrial (Earth-like) planets Mercury, Venus, Earth, and Mars. Mercury, the nearest to the Sun,

Artist's rendition of the formation of the solar system. Scientists theorize that the system began as a nebula, a spinning cloud of gas and dust that collapsed under its own weight, forming the Sun at the center. The planets are believed to have formed from dustballs that were then melted into rocky spheres by bolts of lightning. (Painting by Don Dixon, NASA)



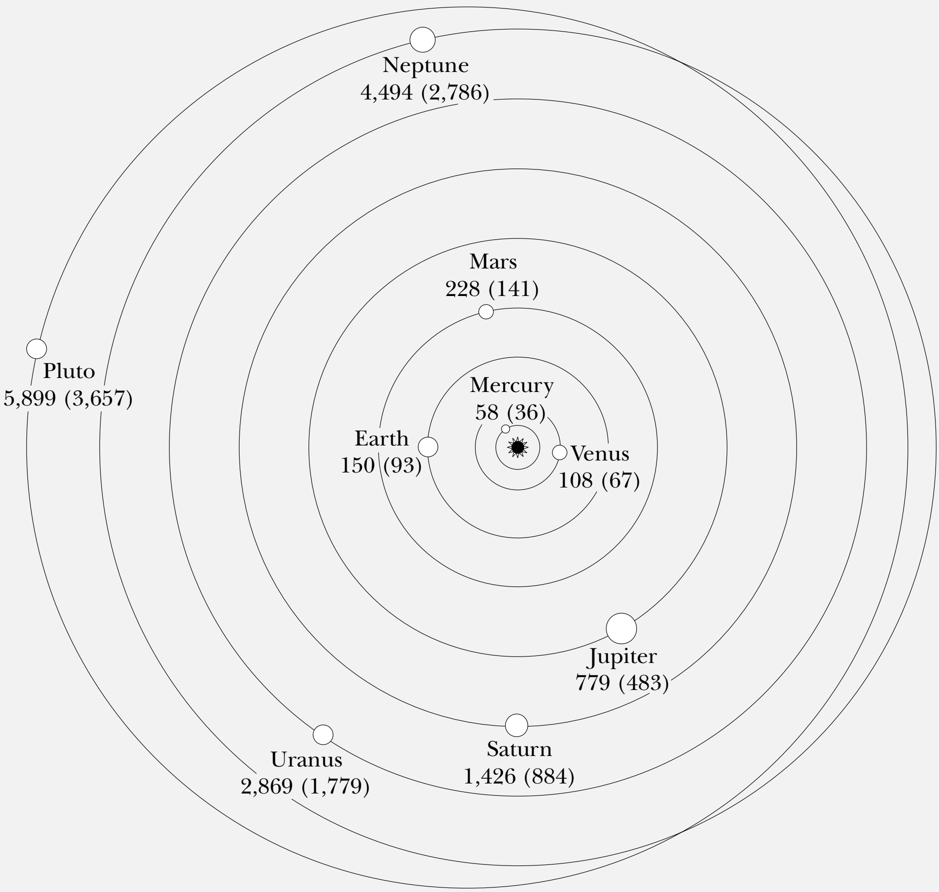
Note: The size of the Sun and distances between planets are not to scale.

orbits at an average distance of 36 million miles (58 million km.) and Mars, the farthest, at 142 million miles (228 million km.). Astronomers call the distance from the Sun to Earth (93 million miles/150 million km.) an astronomical unit (AU) and use it to measure planetary distances.

Terrestrial planets are rocky and warm and have cores of dense metal. All four planets have volcanoes, which long ago spewed out gases that cre-

Composite picture (not to scale) with photographs of the Solar System's planets, showing their relative positions, from closest to most distant from the Sun. Earth (with its Moon to the right) is the third from the top. (PhotoDisc)

DISTANCES OF PLANETS FROM THE SUN IN MILLIONS OF KILOMETERS (MILES)



Source: Data are from Jet Propulsion Laboratory, California Institute of Technology. *The Deep Space Network*. Pasadena, Calif.: JPL, 1988, p. 17.

ated atmospheres on all but Mercury, which is too close to the Sun to hold onto an atmosphere. Mercury is heavily cratered, like the earth's moon. Venus has a permanent thick cloud cover and a surface temperature hot enough to melt lead. The air on Mars is very thin and usually cold, made mostly of carbon dioxide. Its dry, rock-strewn surface has many craters. It also has the largest known volcano in the solar system, Olympus Mons, which is 16 miles (25 km.) high.

Average temperatures and air pressures on Earth allow liquid water to

Among the Solar System's other planets, Mars is the one that most resembles Earth. (PhotoDisc)

collect on the surface, a unique feature among planets within the solar system. Meanwhile, Earth's atmosphere—mostly nitrogen and oxygen—and a strong magnetic field protect the surface from harmful solar radiation. These are the conditions that nurture life, according to scientists. Mars also might have had such conditions long ago. Space probes have photographed features there that look like river channels and lake beds, and scientists think the Martian atmosphere was much thicker at one time. Like Earth, Mars has polar ice caps, although those on Mars are made up mostly of carbon dioxide ice (dry ice), while those on Earth are made up of water ice.

A single natural satellite, the Moon, orbits Earth, probably created by a collision with a huge planetesimal more than four billion years ago. Mars has two tiny moons that may have drifted to it from the asteroid belt. A broad ring from 2 to 3.3 AU from the Sun, this belt is composed of space rocks as small as dust grains and as large as 600 miles (1,000 km.) in diam-

Other Earths

By the end of the twentieth century, astronomers had detected twenty-eight planets circling stars in the Sun's neighborhood of the galaxy. Planets, they think, are common. Those found were all gas giants the size of Saturn or larger. Earth-size planets are much too small to spot at such great distances. Where there are gas giants, there also may be terrestrial dwarfs, as in Earth's solar system. Where there are terrestrial planets, there may be liquid water and, possibly, life.

eter. Asteroids are made of mineral compounds, especially those containing iron, carbon, and silicon. Although the asteroid belt contains enough material for a planet, one did not form there because Jupiter's gravity prevented the asteroids from crashing together. The belt separates the first region of the solar system from the second.

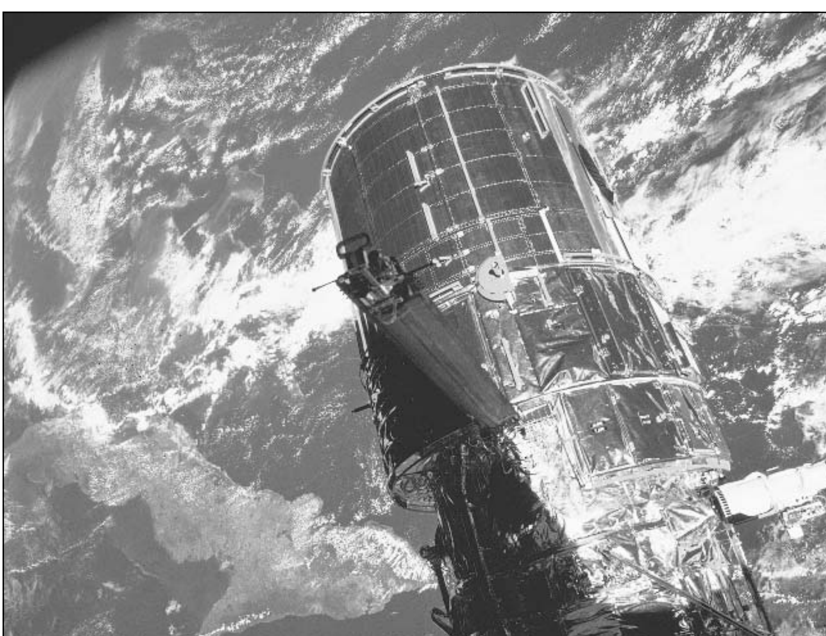
The Giant Planets. The second region belongs to the gas giants Jupiter, Saturn, Uranus, and Neptune. The closest, Jupiter, is 5.2 AU from the Sun, and the most distant, Neptune, is 30.11 AU. Jupiter is the largest planet in the solar system, its diameter 109 times larger than Earth's. The giant planets have solid cores, but most of their immense size is taken up by hydrogen, helium, and methane gases that grow thicker and thicker until they are like sludge near the core. On Jupiter, Saturn, and Uranus, the gases form wide bands over the surface. The bands sometimes have immense circular storms like hurricanes, but hundreds of times larger. The Great Red Spot of Jupiter is an example. It has winds of up to 250 miles (400 km.) per hour, and is at least a century old.

A gas giant, Jupiter is the largest planet in the solar system. Although it has a solid core, most of its immense size is taken up by hydrogen, helium, and methane gases that grow thicker and thicker until they are like sludge near the core. Jupiter's famous Great Red Spot is actually an immense, centuries-old circular storm in a band of surface gases, with winds of up to 250 miles (400 km) per hour. (PhotoDisc)

These planets have such strong gravity that each has attracted many moons to orbit it. In fact, they are like miniature solar systems. Jupiter has the most moons—eighteen—and Neptune has the fewest—eight—but Neptune's moon Triton is the largest of all. Most moons are balls of ice and rock, but Jupiter's Europa and Saturn's Titan may have liquid water below ice-bound surfaces. Several moons appear to have volcanoes, and a wispy atmosphere covers Titan. Additionally, the giant planets have rings of broken rock and ice around them, no more than 330 feet (100 meters) thick. Saturn's hundreds of rings are the brightest and most famous.

The Kuiper Belt. The third region of the solar system, the Kuiper Belt, contains the ninth planet from the Sun, Pluto. Pluto has a single moon, Charon. It does not orbit on the same plane, called the ecliptic, as the rest of the planets do. Instead, its orbit diverges more than seventeen degrees above and below the ecliptic. Its orbit's oval shape brings Pluto within the orbit of Neptune for a large percentage of its long year, which is equal to 248 Earth years. Two-thirds the size of the earth's moon, Pluto has a thin, frigid methane atmosphere. Charon is half Pluto's size and orbits less than 32,000 miles (20,000 km.) from Pluto's surface. Because of the closeness in the sizes of Pluto and Charon, some astronomers consider them to be a double planet.

Many astronomers have not regarded Pluto as a true planet at all. They



The Hubble Telescope, which was placed in orbit in 1990, has made possible revolutionary advances in telescopic space exploration. (PhotoDisc) instead have thought of it as merely the largest of several dozen icy bodies discovered in the Kuiper Belt. The Kuiper Belt holds asteroids and the "short-period" comets that pass by Earth in orbits of twenty to two hundred years. These bodies are the remains of planet formation and did not collect into planets because distances between them are too great for many collisions to occur. Most of them are loosely compacted bodies of ice and mineral—"dirty snowballs," in the words of a famous astronomer. An estimated 200 million Kuiper Belt objects orbit within a band of space from 30 to 50 AU from the Sun.

The Oort Cloud. In contrast to the other regions of the solar system, the Oort Cloud is a spherical shell surrounding the entire solar system. It is also a collection of comets—as many as two trillion, scientists calculate. The inner edge of the cloud forms at a distance of about 20,000 AU from the Sun and extends as far out as 100,000 AU. The Oort Cloud thus gives the solar system a theoretical diameter of 200,000 AU—a distance so vast that light needs more than three years to cross it. No astronomer has yet detected an Oort Cloud object, because the cloud is so far away. Occasionally, however, gravity from a nearby star dislodges an object in the cloud, causing it to fall toward the Sun. When observers on Earth see such an object sweep by in a long, cigar-shaped orbit, they call it a long-period comet. The outer edge of the Oort Cloud marks the farthest reach of the Sun's gravitational power to bind bodies to it. In one respect, the Oort Cloud is part of interstellar space.

In addition to light, the Sun sends out a constant stream of charged particles—atoms and subatomic particles—called the solar wind. The solar wind shields the solar system from the interstellar medium, but it only does so out to about 100 AU, a boundary called the heliopause. That is a small fraction of the distance to the Oort Cloud.

Roger Smith

Information on the World Wide Web

The Web site of the Lunar and Planetary Institute, a NASA-funded institute in Houston, Texas, devoted to the study of the solar system, has current data and photos, many from space probes. (www.lpi.usra.edu)

The Planetary Society, a nonprofit, nongovernmental organization founded in 1980 by Carl Sagan, Bruce Murray, and Louis Friedman, encourages the exploration of the solar system and the search for extraterrestrial life. The society's Web site features recent planetary news stories, an interactive learning center, and links to other space exploration sites. (planetary.org)

Views of the Solar System is an educational, interactive Web site sponsored by the Hawaiian Astronomical Society. (www.solarviews.com/ss.html).

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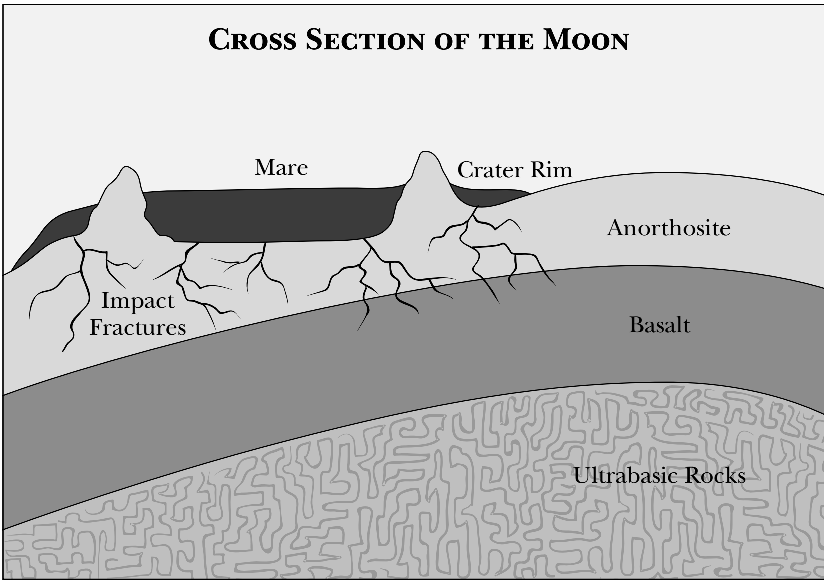
Earth's Moon

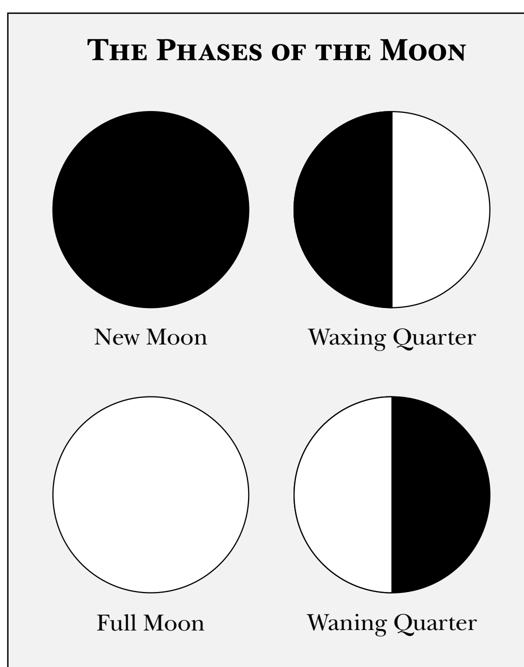
The fourth largest natural satellite in the solar system, Earth's moon has a diameter of 2,160 miles (3,476 km.)—less than one-quarter the diameter of Earth. The Moon's mass is less than one-eightieth that of Earth.

The Moon orbits Earth in an elliptical path. When it is at perigee (when it is closest to Earth), it is 221,473 miles (356,410 km.) distant. When it is at apogee (farthest from Earth), it is 252,722 miles (406,697 km.) distant.

The Moon, viewed over the shoulder of Washington's Mount Rainier in the Cascade Range. (PhotoDisc)



The Moon completes one orbit around Earth every 27.3 Earth days. Because it rotates at about the same rate that it orbits the earth, observers on Earth only see one side of the Moon. The changing angles between Earth, the Sun, and the Moon determine how much of the Moon's illuminated surface can be seen from Earth and cause the Moon's changing phases.



Volcanism. Naked-eye observations of the Moon from Earth reveal dark areas called *maria*, the plural form of the Latin word *mare* for sea. The maria are the remains of ancient lava flows from inside gigantic impact craters; the last eruptions were more than three billion years ago. The lava consists of basalt, similar in composition to Earth's oceanic crust and many volcanoes. The maria have names such as Mare Serenitatis (15 to 40 degrees north latitude, longitude 5 to 20 degrees east) and Mare Tranquillitatis (0 to 20 degrees north latitude, longitude 15 to 45 degrees east). Some of the smaller dark areas on the Moon also have names that are water-related: lacus (lake), sinus (bay), and palus (marsh).

Impact Craters. Observing the Moon with an optical aid, such as a telescope or a pair of binoculars, provides a closer view of impact craters. Impact craters of various sizes cover 83 percent of the Moon's surface. More than 33,000 craters have been counted on the Moon.

One of the easiest craters to observe from the Earth is Tycho. Located at 43.3 degrees south latitude, longitude 11.2 degrees west, it is about 50 miles (85 km.) wide. Surrounding Tycho are rays of dusty material, known as ejecta, that appear to radiate from the crater. When an object from space, such as a meteoroid, slams into the Moon's surface, it is vaporized upon impact. The dust and debris from the interior of the crater fall back onto the lunar surface in a pattern of rays. Because the ejecta is disrupted by subsequent impacts, only the youngest craters still have rays.

Earth's Moon, showing impact craters. (PhotoDisc)

Earthrise, as seen from the surface of the Moon. (PhotoDisc)

ECLIPSES

The Sun's diameter is four hundred times larger than the Moon's; however, the Moon is four hundred times closer to Earth than the Sun, making the two objects appear nearly the same size in the sky to observers on Earth. As the Moon orbits Earth, it crosses the plane of the Earth-Sun orbit twice each month. If one of the orbit-crossing points (called nodes) occurs during a new or full moon phase, a solar or lunar eclipse can occur.

A solar eclipse occurs when the Moon and the Sun appear to be in the exact same place in the sky during a new moon phase. When that happens, the Moon blocks the light of the Sun for up to seven minutes. Because solar eclipses can be seen only from certain places on Earth, some people travel around the world—sometimes to remote places—to view them.

A lunar eclipse occurs when Earth is positioned between the Sun and the Moon and casts its shadow on the Moon. In contrast to solar eclipses, lunar eclipses are visible from every place on Earth from which the Moon can be seen.

Apollo 17 astronaut collecting soil samples on the moon in December, 1972. (Corbis)

Sometimes, pieces of the ejecta fall back and create smaller craters called secondary craters. The ejecta rays of Tycho extend to almost 1,865 miles (3,000 km.) beyond the crater's edge.

Other Lunar Features. Near the crater called Archimedes is the Apennines mountain range, which has peaks nearly 20,000 feet (60,000 meters) high—altitudes comparable to South America's Andes.

The Moon also has valleys. Two of the most well known are the Alpine Valley, which is about 115 miles (185 km.) long; and the Rheita Valley, located about 155 miles (250 km.) from the Stevinus crater, which is 238 miles (383 km.) long, 15.5 miles (25 km.) wide, and 2,000 feet (609 meters) deep.

Smaller than valleys and resembling cracks in the lunar surface are features called rilles, which are thought to be places of ancient lava flow. Many rilles can be seen near the Aristarchus crater. Rilles are often up to 3 miles (5 km.) wide and can stretch for more than 104 miles (167 km.).

A wrinkle in the lunar surface is called a ridge. Many ridges are found around the boundaries of the maria. The Serpentine Ridge cuts through Mare Serenitatis.

Exploration of the Moon. Robotic spacecraft were the first visitors to explore the Moon. The Russian spacecraft Luna 1 made the first flyby of the Moon in January, 1959. Eight months later, Luna 2 made the first impact on the Moon's surface. In October, 1959, Luna 3 was the first spacecraft to photograph the side of the Moon not visible from Earth. In 1994 the United States' *Clementine* spacecraft was the first probe to map the Moon's composition and topography globally.

The first humans to land on the Moon were the U.S. astronauts Neil Armstrong and Edwin "Buzz" Aldrin. On July 20, 1969, they landed in the *Eagle* lunar module, during the Apollo 11 mission. Armstrong's famous statement, "That's one small step for man, one giant leap for mankind," was heard around the world by millions of people who watched the first humans set foot on the lunar surface, at the Sea of Tranquillity. The last twentieth century human mission to reach the lunar surface, Apollo 17, landed there in December, 1972. Astronauts Gene Cernan and geologist Jack Schmitt landed in the Taurus-Littrow Valley (20 degrees north latitude, longitude 31 degrees east).

Noreen A. Grice

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NASA's Spacelink education Web site, featuring educational services, instructional materials, and news about NASA projects, is a good starting place from which to find information about the Moon. (spacelink.nasa.gov/.index.html)

The Sun and the Earth

Of all the astronomical phenomena that one can consider, few are more important to the survival of life on Earth than the relationship between Earth and the Sun. With the exception of small amounts of residual (endogenic) energy that have remained inside the earth from the time of its formation some 4.5 billion years ago and which sustain some specialized forms of life along some oceanic rift systems, almost all other forms of life, including human, depend on the exogenic light and energy that the earth receives directly from the Sun.

The various ecosystems on Earth are highly dependent on the angles at which the Sun's rays strike Earth's spherical surface. These angles, which vary greatly with latitude and time of year, determine many commonly observed phenomena, such as the height of the Sun above the horizon, the changing lengths of day and night throughout the year, and the rhythm of the seasons. Daily and seasonal changes have profound effects on the many climatic regions and life cycles found on earth.

The Sun. The center of Earth's solar system, the Sun is but one ordinary star among some 100 billion stars in an ordinary cluster of stars called the Milky Way galaxy. There are at least ten billion galaxies in the universe, each with billions of stars. Statistically, the chances are good that many of these stars have their own solar systems. Late twentieth century astronomical observations discovered the presence of what appear to be planets, large ones similar in size to Jupiter, orbiting other stars.

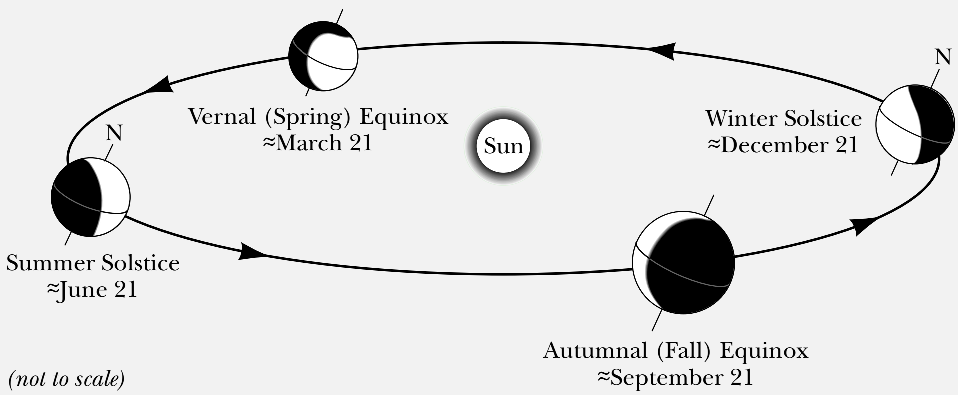
Earth's Sun is an average star in terms of its physical characteristics. It is a large sphere of incandescent gas that has a diameter more than 100 times that of Earth, a mass more than 300,000 times that of Earth, and a volume 1.3 million times that of Earth. The Sun's surface gravity is thirty-four times that of Earth.

The conversion of hydrogen into helium in the Sun's interior, a process known as nuclear fusion, is the source of the Sun's energy. The amount of mass that is lost in the fusion process is miniscule, as evidenced by the fact that it will take perhaps 15 million years for the Sun to lose one-millionth of its total mass. The Sun is expected to continue shining through another several billion years.

Earth Revolution. The earth moves about the Sun in a slightly elliptical orbit called a revolution. It takes one year for the earth to make one revolution at an average orbital velocity of about 18.5 miles per second (29.6 kilometers per second). Earth-sun relationships are described by a tropical year, which is defined as the period of time (365.25 average solar days) from one vernal equinox to another. To balance the tropical year with the calendar year, a whole day (February 29) is added every fourth year (leap year). Other minor adjustments are necessary so as to balance the system.

Perihelion and Aphelion. The average distance between Earth and the Sun is approximately 93 million miles (150 million km.). At that distance, sunlight, which travels at the speed of light (186,000 miles/300,000 kilometers per second), takes about 8.3 minutes to reach the earth. Since the earth's orbit is an ellipse rather than a circle, the earth is closest to the Sun on about January 3—a distance of 91.5 million miles (147 million km.). This position in space is called perihelion, which comes from the Greek *peri,* meaning "around" or "near," and *helios,* meaning the Sun. Earth is farthest from the Sun on about July 4 at aphelion (Greek *ap,*

Earth's Orbit Around the Sun



"away from," and *helios*), with a distance of 94.5 million miles (152 million kilometers).

Axial Inclination. Astronomers call the imaginary surface on which Earth orbits around the Sun the plane of the ecliptic. The earth's axis is inclined 66.5 degrees to the plane of the ecliptic (or 23.5 degrees from the perpendicular to the plane of the ecliptic), and it maintains this orientation with respect to the stars. Thus, the North Pole points in the same direction to Polaris, the North Star, as it revolves about the Sun. Consequently, the Northern Hemisphere tilts away from the Sun during one-half of Earth's orbit and toward the Sun through the other half.

Winter solstice occurs on about December 22, when the tilt of the Northern Hemisphere away from the Sun is at its maximum. The opposite condition occurs during summer solstice on about June 21, when the Northern Hemisphere reaches its maximum tilt toward the Sun. The equinoxes occur midway between the solstices when neither the Southern nor the Northern Hemisphere is tilted toward the Sun. The vernal and autumnal equinoxes occur on about March 21 and September 23, respectively.

The axial inclination of 66.6 degrees (or 23.5 degrees from the perpendicular) explains the significance of certain parallels on the earth. The noon sun shines directly overhead on the earth at varying latitudes on different days—between 23.5 degrees south latitude and 23.5 degrees north latitude. The parallels at 23.5 degrees south latitude and 23.5 degrees north latitude are called the Tropics of Capricorn and Cancer, respectively.

During the winter and summer solstices, the area on the earth between the Arctic Circle (at 66.5 degrees north latitude) and the North

Pole has twenty-four hours of darkness and daylight, respectively. The same phenomena occurs for the area between the Antarctic Circle (at 66.5 degrees south latitude) and the South Pole, except that the seasons are reversed in the Southern Hemisphere. At the poles, the Sun is below the horizon for six months of the year.

For those living outside the Tropics (poleward of 23.5 degrees north and south latitude), the noon sun will never shine directly overhead. Hours of daylight will also vary greatly during the year. For example, daylight will range from approximately nine hours during the winter solstice to fifteen hours during the summer solstice for persons living near 40 degrees north latitude, such as in Philadelphia, Denver, Madrid, and Beijing.

Solar Radiation. Given the size of the earth and its distance from the Sun, it is estimated that this planet receives only about one two-billionth part of the total energy released by the Sun. However, this seemingly small amount is enough to drive the massive oceanic and atmospheric circulation systems and to support all life processes on Earth.

Solar energy is not evenly distributed on Earth. The higher the angle of the Sun in the sky, the greater the duration and intensity of the insolation. To illustrate this, note how easy it is look at the Sun when it is very low on the horizon—near dawn and sunset. At those times, the Sun's rays have to penetrate much more of the atmosphere, so more of the sunlight is absorbed. When the Sun's rays are coming in at a low angle, the same solar energy is spread over a larger area, thereby leading to less insolation per unit of area. Thus, the equatorial region receives much more solar energy than the polar region. This radiation imbalance would make the earth decidedly less habitable were it not for the atmospheric and oceanic circulation systems (such as the warm Gulf Stream) that move the excess heat from the Tropics to the middle and high latitudes.

Robert M. Hordon

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The Seasons

Earth's 365-day year is divided into seasons. In most parts of the world, there are four seasons—winter, spring, summer, and fall (also called autumn). In some tropical regions—those close to the equator—there are only two seasons. In areas close to the equator, temperatures change little throughout the year; however, amounts of rainfall vary greatly, resulting in distinct wet and dry seasons. The polar regions of the Arctic and Antarctic also have little variation in temperature, remaining cold throughout the year. Their seasons are light and dark, because the Sun shines almost constantly in the summer and hardly at all in the winter.

The four seasons that occur throughout the northern and southern temperate zones—between the Tropics and the polar regions—are climatic seasons, based on temperature and weather changes. Winter is the coldest season; it is the time when days are short and few crops can be grown. It is followed by spring, when the days lengthen and the earth warms; this is the time when planting typically begins, and animals that hibernate (from the French word for winter) during the winter leave their dens.

Summer is the hottest time of the year. In many areas, summer is marked by drought, but other regions experience frequent thunderstorms and humid air. In the fall, the days again become shorter and cooler. This is the time when many crops are harvested. In ancient cultures, the turning of the seasons was marked by festivals, acknowledging the importance of seasonal changes to the community's survival.

Each season is defined as lasting three months. Winter begins at the winter solstice, which is the time when the Sun is farthest from the equator. In the Northern Hemisphere, this occurs on about December 21, when the Sun is directly over the tropic of Capricorn. Summer begins at the other solstice, on about June 21 in the Northern Hemisphere, when the Sun is directly over the tropic of Cancer. The winter solstice is the shortest day of the year; the summer solstice is the longest.

Spring and fall begin on the two equinoxes. At an equinox, the Sun is directly above the earth's equator and the lengths of day and night are approximately equal everywhere on Earth. In the Northern Hemisphere, the vernal (spring) equinox occurs on about March 21, and the autumnal equinox occurs on about September 23.

Seasons and the Hemispheres. The relationship of the seasons to the calendar is opposite in the Northern and Southern Hemispheres. On the day that a summer solstice occurs in the Northern Hemisphere, the winter solstice occurs in the Southern Hemisphere. Thus, when it is summer in the Southern Hemisphere, it is winter in the Northern Hemisphere, and vice versa.

The Sun and the Seasons. The reason why summers and winters differ in the temperate zones is often misunderstood. Many people think that winter happens when the Sun is more distant from the earth than it is in summer. What causes Earth's seasons is not the changing distances between the earth and the Sun, but the tilt of the earth's axis. A line drawn from the North Pole to the South Pole through the center of the earth (the earth's axis) is not perpendicular to the plane of the earth's orbit (the ecliptic). The earth's axis and the perpendicular to the ecliptic make an angle of 23.5 degrees. This tilts the Northern Hemisphere toward the Sun when the earth is on one side of its orbit around the Sun, and tilts the Southern Hemisphere toward the Sun when the earth moves around to the Sun's opposite side. When the Sun appears to be at its highest in the sky, and its rays are most direct, summer occurs. When the Sun appears to be at its lowest, and its rays are indirect, there is winter.

Local Phenomena. Local conditions can have important effects on seasonal weather. At locations near oceans, sea breezes develop during the day, and evenings are characterized by land breezes. Sea breezes bring cooler ocean air in toward land. This results in temperatures at the shore often being 5 to 11 degrees Fahrenheit (3 to 6 degrees Celsius) lower than temperatures a few miles inland.

At night, when land temperatures are lower than ocean temperatures, land breezes move air from the land toward the water. As a result, coastal regions have less seasonal temperature variations than inland areas do. For example, coastal areas seldom become cold enough to have snow in the winter, even though inland areas at the same latitude do.

Hailstorms. Hail usually occurs during the summer, and is associated with towering thunderstorm clouds, called cumulonimbus. Hail is occasionally confused with sleet. Sleet is a wintertime event, and occurs when warmer layers of air sit above freezing layers near the ground. Rain that forms in the warmer, upper layer solidifies into tiny ice pellets in the lower, subfreezing layer before hitting the ground.

Hail is an entirely different phenomenon. When cold air plows into warmer, moist air—called a cold front boundary—powerful updrafts of rising air can be created. The warm, moist air propelled upward by the heavier cold air can reach velocities approaching 100 miles (160 kilometers) per hour. Ice crystals form above the freezing level in the cumulonimbus clouds and fall into lower, warmer parts of the clouds, where they become coated with water. Picked up by an updraft, the coated ice crystals are carried back to a higher, colder levels where their water coatings freeze. This cycle can repeat many times, producing hailstones that have multiple, concentric layers of ice.

Hailstorms can be very damaging. Hail can ruin crops, dent car bodies, crack windshields, and injure people. The Midwest region of the United States is particularly susceptible to hailstorms. There, warm, moist air from the Gulf of Mexico often meets much colder, drier air originating in Canada. This combination produces the extreme atmospheric instability necessary for that kind of weather.

Alvin S. Konigsberg

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Earth's Interior

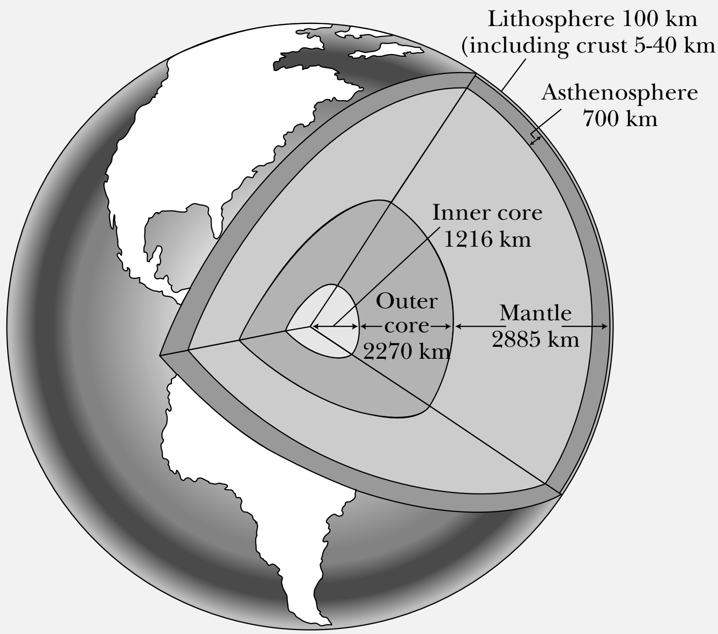
Earth's Internal Structure

Earth is one of the nine known planets in the Sun's solar system that formed from a giant cloud of cosmic dust called a nebula. This event is thought to have happened between 4.44 billion years ago (based on the age of the oldest-known Moon rock) and 4.56 billion years ago (the age of meteorite bombardment). After Earth's formation, heat released by colliding particles combined with the heat energy released by the decay of radioactive elements to cause some or all of Earth's interior to melt. This melting began the process of differentiation, which allowed the heavier elements, mainly iron and nickel, to sink toward Earth's center while the lighter, rocky components moved upward, as a result of the contrast in density of the earth's forming elements.

This process of differentiation was probably the most important event of Earth's early history. It changed the planet from a homogeneous mixture with neither continents nor oceans to a planet with three layers: a dense core beginning at 1,800 miles (2,900 km.) deep and ending at Earth's center, 3,977 miles (6,400 km.) below the surface; a mantle beginning between 3 and 44 miles (5-70 km.) deep and ending at Earth's core; and a crust going from Earth's surface to about 3-6 miles (5-10 km.) deep for oceanic crust and 22-44 miles (35-70 km.) deep for continental crust.

Layering of the Earth. Earth's layers can be classified either by their composition (the traditional method) or by their mechanical behavior (strength). Compositional classification identifies several distinct concentric layers, each with its own properties. The outermost layer of Earth is the crust or skin. This is divided into continental and oceanic crusts. The continental crust varies in thickness between 22 and 25 miles (35 and 40 km.) under flat continental regions and up to 44 miles (70 km.) under high mountains. The oceanic crust is made up of igneous rocks rich in iron and magnesium, such as basalt and peridotite. The upper

Earth's Interior



continental crust is composed mainly of alumino-silicates. The oldest continental crustal rock exceeds 3.8 billion years, while oceanic crustal rocks are not older than 180 million years. The oceanic crust is heavier than the continental crust.

Earth's next layer is the mantle, which is made up primarily of ferromagnesium silicates. It is about 1,800 miles (2,900 km.) thick and is separated into the upper and lower mantle. Most of Earth's internal heat is contained within the mantle. Large convective cells in the mantle circulate heat and may drive plate-tectonic processes.

The last layer is the core, which is separated into the liquid outer core and the solid inner core. The outer core is 1,429 miles (2,300 km.) thick, twice as thick as the inner core. The outer core is mainly composed of a nickel-iron alloy, while the inner core is almost entirely composed of iron. Earth's magnetic field is believed to be controlled by the liquid outer core.

In the mechanical layering classification of the earth's interior, the layers are separated based on mechanical properties or strength (resistance to flowing or deformation) in addition to composition. The uppermost layer is the lithosphere (sphere of rock), which comprises the crust and a solid portion of the upper mantle. The lithosphere is divided into many plates that move in relation to each other due to tectonic forces. The solid lithosphere floats atop a semiliquid layer known as the asthenosphere (weak sphere), which enables the lithosphere to move around.

Exploring Earth's Interior. Volcanic activity provides natural samples of the outer 124 miles (200 km.) of Earth's interior. Meteorites—samples of the solar system that have collided with Earth—also provide clues about Earth's composition and early history. The most ambitious human effort to penetrate Earth's interior was made by the former Soviet Union, which drilled a super-deep research well, named the Kola Well, near Murmansk, Russia. This was an attempt to penetrate the crust and reach the upper mantle. The reported depth of the Kola Well is a little more than 7.5 miles (12 km.). Although impressive, the drilled depth represents less than 0.2 percent of the distance from the earth's surface to its center.

A great deal of knowledge about Earth's composition and structure has been obtained through computer modeling, high-pressure laboratory experiments, and meteorites, but most of what is known about Earth's interior has been acquired by studying seismic waves generated by earthquakes and nuclear explosions. As seismic waves are transmitted, reflected, and refracted through the earth, they carry information to the surface about the materials through which they have traveled. Seismic waves are recorded at receiver stations (seismographic stations) and processed to provide a picturelike image of Earth's interior.

Changes in P- and S-wave velocities within Earth reveal the sequence of layers that make up Earth's interior. P-wave velocity depends on the elasticity, rigidity, and density of the material. By contrast, S-wave velocity depends only on the rigidity and density of the material. There are sharp variations in velocity at different depths, which correspond to boundaries between the different layers of Earth. P-wave velocity within crustal rocks ranges from 3.6-4.2 miles (6-7 km.) per second.

The boundary between the crust and the mantle is called the Mohorovičić discontinuity or Moho. At Moho, P-wave velocity increases from 4.2-4.8 miles (7-8 km.) per second. Beyond the crust-mantle boundary, P-wave velocity increases gradually up to about 8.1 miles (13.5 km.) per second at the core-mantle boundary. At this depth, S-waves are not transmitted and P-wave velocity, decreases from 8.1 to 4.8 miles (13.5 to 8 km.) per second, which strongly supports the concept that the outer core is liquid, since S-waves cannot travel through liquids. As P-waves enter the inner core, their velocity again increases, to about 6.8 miles (11.3 km.) per second.

Earth's interior seems to be characterized by a gradual increase with depth in temperature, pressure, and density. Extensive experimental and modeling work indicates that the temperature at 62 miles (100 km.) is between 2,192 to 2,552 degrees Fahrenheit (1,200 and 1,400 degrees Celsius). The temperature at the core-mantle boundary—about 1,802 miles

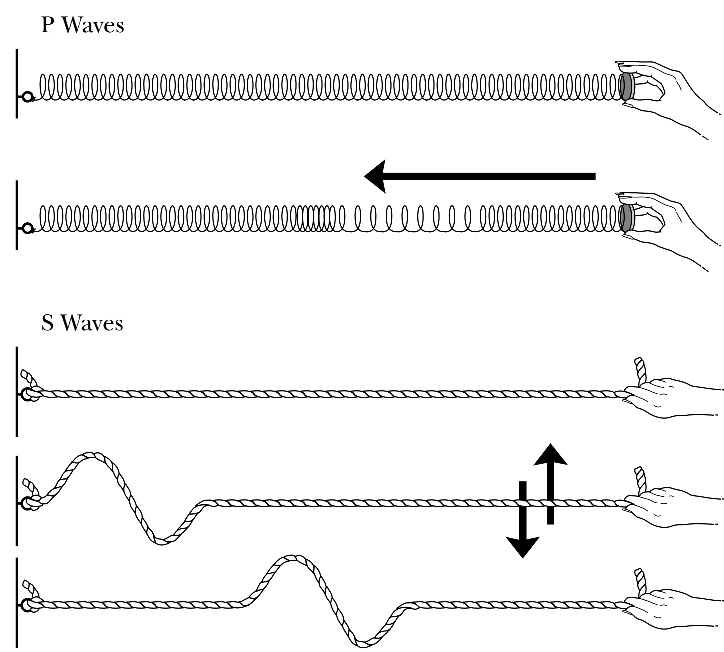
(2,900 km.) deep—is calculated to be about 8,130 degrees Fahrenheit (4,500 degrees Celsius). At Earth's center the temperature may exceed 12,092 degrees Fahrenheit (6,700 degrees Celsius). Although at Earth's surface, heat energy is slowly but continuously lost as a result of outgassing, such as from volcanic eruptions, its interior remains hot.

Properties of Seismic Waves

Seismologists use two types of body waves—primary (P-waves) and secondary (S-waves) waves—to estimate seismic velocities of the different layers within the earth. In most rock types P-waves travel between 1.7 and 1.8 times more quickly than S-waves; therefore, P-waves always arrive first at seismographic stations. P-waves travel by a series of compressions and expansions of the material through which they travel. P-waves can travel through solids, liquids, or gases. When P-waves travel in air, they are called sound waves.

The slower S-waves, also called shear waves, move like a wave in a rope. This movement makes the S-wave more destructive to structures like buildings and highway overpasses during earthquakes. Because S-waves can travel only through solids and cannot travel through Earth's outer core, seismologists concluded that Earth's outer core must be liquid or at least must have the properties of a fluid.

Movement of Seismic Waves



Seismic Tomography and Future Exploration. Seismic tomography is one of the newest tools that earth scientists are using to develop three-dimensional velocity images of Earth's interior. In seismic tomography, several crossing seismic waves from different sources (earthquakes and nuclear explosions) are analyzed in much the same way that computerized axial tomography (CAT) scanners are used in medicine to obtain images of human organs. Seismic tomography is providing two- and three-dimensional images from the crust to the core-mantle boundary. Fast P-wave velocities have been correlated to cool material—for example, a piece of sinking lithosphere (cool rigid layer) such as in regions underneath the Andes Mountains (subduction zone); slow P-wave velocities have been correlated with hot materials—for example, rising mantle plumes of hot spots such as the one responsible for volcanic activity in the Hawaiian Islands.

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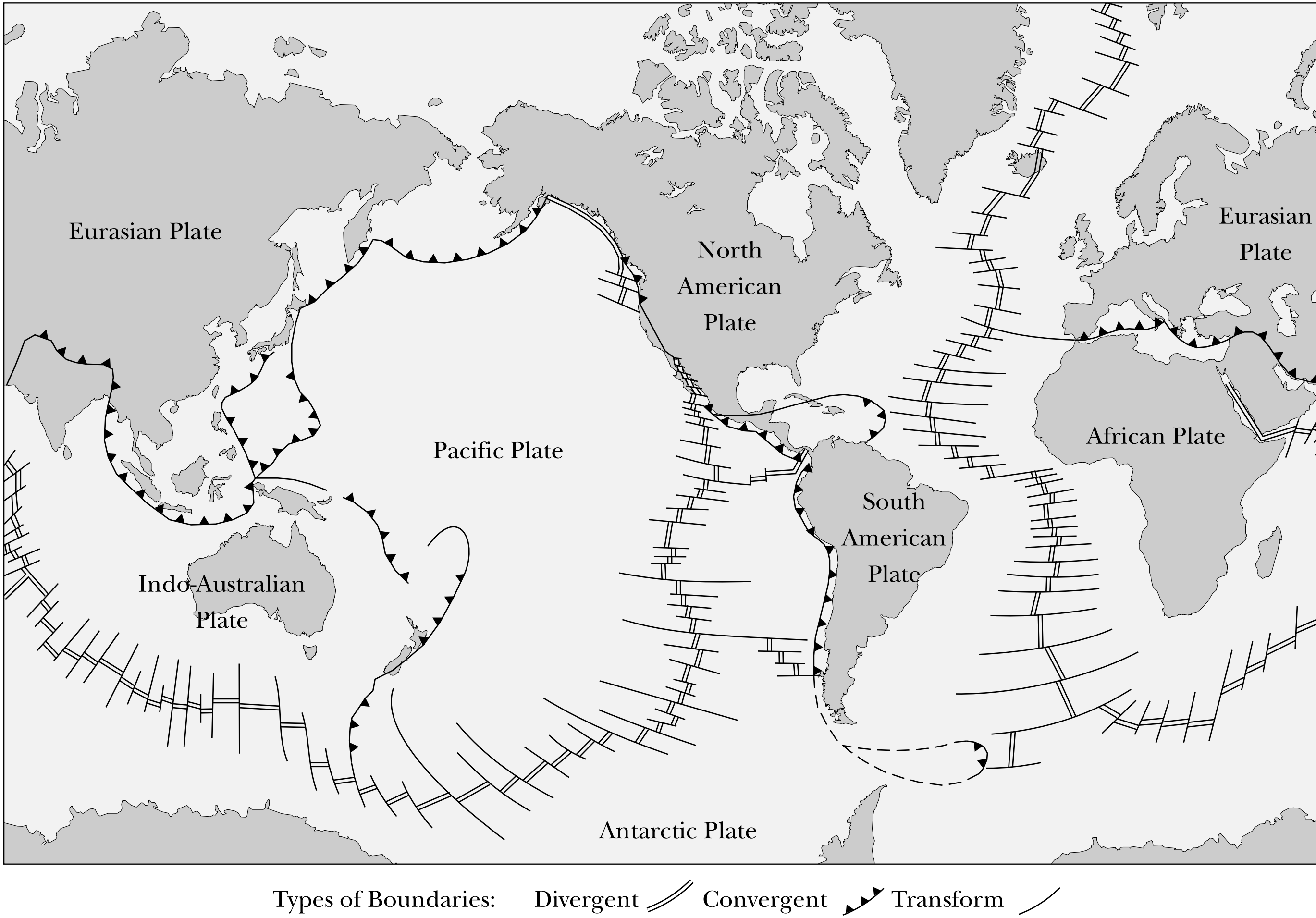
Plate Tectonics

The theory of plate tectonics provides an explanation for the present-day structure of the large landforms that constitute the outer part of the earth. The theory accounts for the global distribution of continents, mountains, hills, valleys, plains, earthquake activity, and volcanism, as well as various associations of igneous, metamorphic, and sedimentary rocks, the formation and location of mineral resources, and the geology

Major Tectonic Plates and Mid-Ocean Ridges



of ocean basins. Everything about the earth is related either directly or indirectly to plate tectonics.

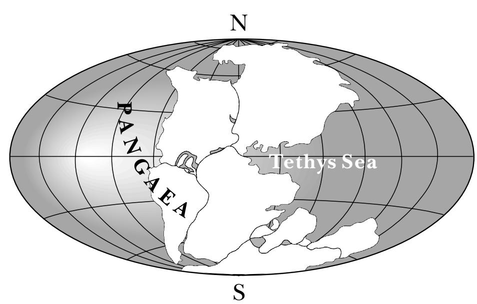
Basic Theory. Plate-tectonic theory is based on an Earth model in which a rigid, outer shell—the lithosphere—lies above a hotter, weaker, partially molten part of the mantle called the asthenosphere. The lithosphere varies in thickness between 6 and 90 miles (10 and 150 km.), and comprises the crust and the underlying, upper mantle. The asthenosphere extends from the base of the lithosphere to a depth of about 420 miles (700 km.). The brittle lithosphere is broken into a pattern of internally rigid plates that move horizontally relative to each other across the earth's surface.

More than a dozen plates have been distinguished, some extending more than 2,500 miles (4,000 km.) across. Exhibiting independent mo-

The Supercontinents

The theory of plate tectonics explains the present-day distribution of major landforms, seismic and volcanic activity, and physiographic features of ocean basins. Many scientists also use the theory to explain the history of Earth's surface. Evidence indicates that the modern continents once formed a single landmass called Pangaea, meaning "all lands." According to the theory of plate tectonics, approximately 200 million years ago Pangaea began to split into two supercontinents, Laurasia and Gondwanaland. Eventually, as a result of tectonic forces, Laurasia split into North America, Europe, and most of Asia. Gondwanaland broke up into India, South America, Africa, Australia, and Antarctica.

Pangaea



Laurasia and Gondwanaland

tion, the plates grind and scrape against each other, similar to chunks of ice in water, or like giant rafts cruising slowly on the asthenosphere. Most of the earth's dynamic activity, including earthquakes and volcanism, occurs along plate boundaries. The global distribution of these tectonic phenomena delineates the boundaries of the plates.

Geological observations, geophysical data, and theoretical models support the existence of three types of plate boundaries. Divergent boundaries occur where adjacent plates move away from each other. Convergent boundaries occur where adjacent plates move toward each other. Transform boundaries occur where plates slip past one another in directions parallel to their common boundaries.

The continents were formed by the movement at plate boundaries, and continental landforms were generated by volcanic eruptions and continental plates colliding with each other. The velocity of plate movement varies from plate to plate and even within portions of the same plate, ranging from 0.8 to 8 inches (2 to 20 centimeters) per year. The rates are calculated from the distance to the midoceanic ridge crests, along with the age of the seafloor as determined by radioactive dating methods.

Convection currents that are driven by heat from radioactive decay in the mantle are important mechanisms involved in moving the huge plates. Convection currents in the earth's mantle carry magma (molten rock) up from the asthenosphere. Some of this magma escapes to form new lithosphere, but the rest spreads out sideways beneath the lithosphere, slowly cooling in the process. Assisted by gravity, the magma flows outward, dragging the overlying lithosphere with it, thus continuing to open the ridges. When the flowing hot rock cools, it becomes dense enough to sink back into the mantle at convergent boundaries.

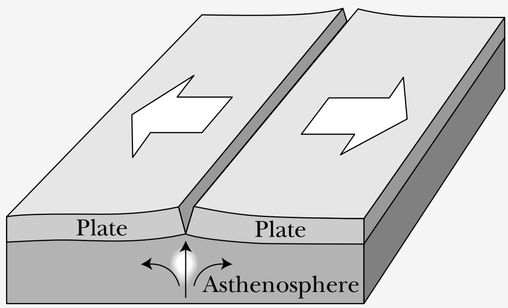
A second plate-driving mechanism is the pull of dense, cold, downflowing lithosphere in a subduction zone on the rest of the trailing plate, further opening up the spreading centers so magma can move upward.

Divergent Plate Boundaries. During the 1950's and 1960's, oceanographic studies revealed that Earth's seafloors were marked by a nearly continuous system of submarine ridges, more than 40,000 miles (64,000 km.) in length. Detailed investigations revealed that the midoceanic ridge system has a central rift valley that runs along its length and that the ridge system is associated with volcanic and earthquake activity. The earthquakes are frequent, shallow, and mild.

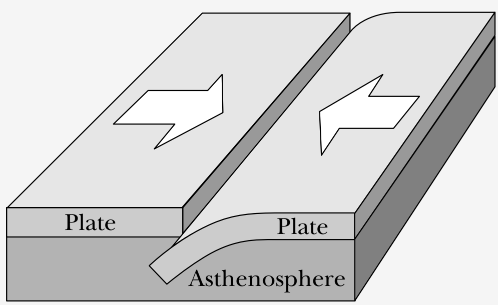
Magnetic studies of the seafloor indicate that the oceanic lithosphere has been segmented into a series of long magnetic strips that run parallel to the axis of the midoceanic ridges. On either side of the ridge, the ocean floor consists of alternating bands of rock, magnetized either parallel to or exactly opposite of the present-day direction of the earth's magnetic field.

Midoceanic ridges, or divergent plate boundaries, are tensional features representing zones of weakness within the earth's crust, where new

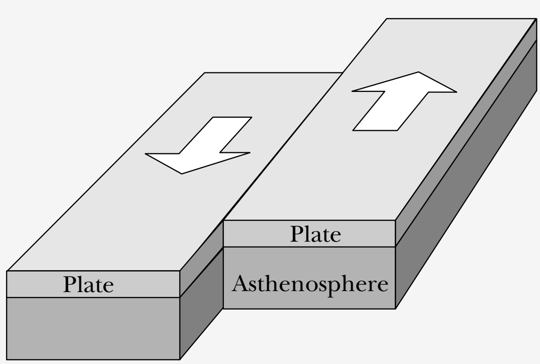
Plate Boundaries



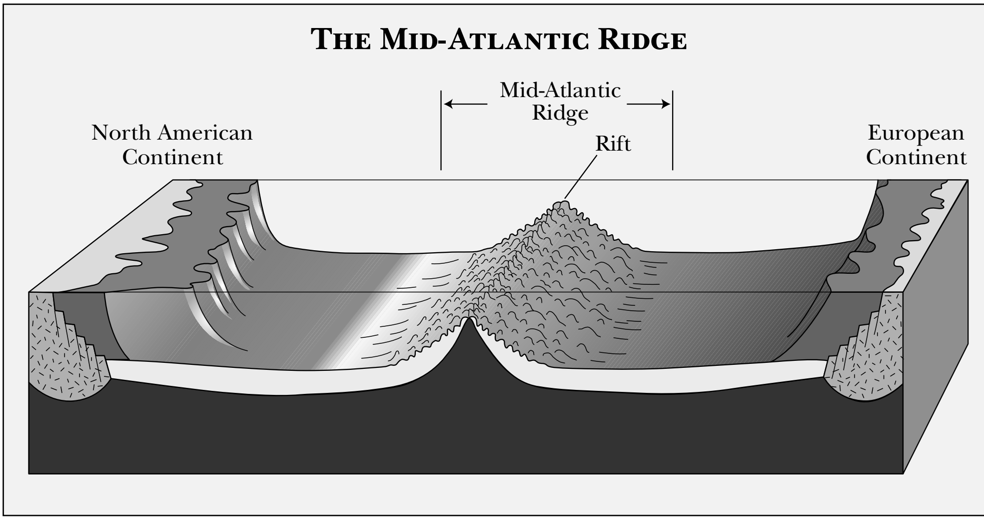
Divergent Boundary



Convergent Boundary



Transform Fault Boundary



The Mid-Atlantic Ridge is a major site of seafloor spreading, where the North American and European plates pull apart.

seafloor is created by the welling up of mantle material from the asthenosphere into cracks along the ridges. As rifting proceeds, magma ascends to fill in the fissures, creating new oceanic crust. Iron minerals within the magma become aligned to the existing Earth polarity as the rock cools and crystallizes. The oceanic floor slowly moves away from the oceanic ridge toward deep ocean trenches, where it descends into the mantle to be melted and recycled to the earth's surface to generate new rocks and landforms.

As the seafloor spreads outward from the rift center, about half of the material is carried to either side of the rift, which is later filled by another influx of molten basalt. When the polarity of the earth changes, the subsequent molten basalt is magnetized in the opposite polarity. The continuation of this process over geologic time leads to the young geologic age of the seafloor and the magnetic symmetry around the midoceanic ridges.

Not all spreading centers are underneath the oceans. An example of continental rifting in its embryonic stage can be observed in the Red Sea, where the Arabian plate has separated from the African plate, creating a new oceanic ridge. Another modern-day example of continental divergent activity is East Africa's Great Rift Valley system. If this rifting continues, it will eventually fragment Africa, producing an ocean that will separate the resulting pieces. Through divergence, large plates are made into smaller ones.

Convergent Plate Boundaries. Because Earth's volume is not changing, the increase in lithosphere created along divergent boundaries must be compensated for by the destruction of lithosphere elsewhere. Otherwise, the radius of Earth would change. The compensation occurs at convergent plate boundaries, where plates are moving together. Three scenarios are possible along convergent boundaries, depending on whether the crust involved is oceanic or continental.

If both converging plates are made of oceanic crust, one will inevitably be older, cooler, and denser than the other. The denser plate eventually subducts beneath the less-dense plate and descends into the asthenosphere. The boundary along the two interacting plates, called a subduction zone, forms a trench. Some trenches are more than 620 miles (1,000 km.) long, 62 miles (100 km.) wide, and 6.8 miles (11 km.) deep. Heated by the hot asthenosphere beneath, the subducted plate becomes hot enough to melt.

Because of buoyancy, some of the melted material rises through fissures and cracks to generate volcanoes along the overlying plate. Over time, other parts of the melted material eventually migrate to a divergent boundary and rise again in cyclic fashion to generate new seafloor. The volcanoes generated along the overriding plate often form a string of islands called island arcs. Japan, the Philippines, the Aleutians, and the Mariannas are good examples of island arcs resulting from subduction of two plates consisting of oceanic lithosphere. Intense earthquakes often occur along subduction zones.

If the leading edge of one of the two convergent plates is oceanic crust and the other is continental crust, the oceanic plate is always the one subducted, because it is always denser. A classic example of this case is the western boundary of South America. On the oceanic side of the boundary, a trench was formed where the oceanic plate plunged underneath the continental plate. On the continental side, a fold mountain belt—the Andes—was formed as the oceanic lithosphere pushed against the continental lithosphere.

When the oceanic plate descends into the mantle, some of the material melts and works its way up through the mountain belt to produce rather violent volcanoes. The boundary between the plates is a region of earthquake activity. The earthquakes range from shallow to relatively deep, and some are quite severe.

The last type of convergent plate boundary involves the collision of two continental masses of lithosphere, which can result in folding, faulting, metamorphism, and volcanic activity. When the plates collide, neither is dense enough to be forced into the asthenosphere. The collision compresses and thickens the continental edges, twisting and deforming the rocks and uplifting the land to form unusually high fold mountain belts. The prototype example is the collision of India with Asia, resulting in the formation of the Himalayas. In this case, the earthquakes are typically shallow, but frequent and severe.

Transform Plate Boundaries. The actual structure of a seafloor spreading ridge is more complex than a single, straight crack. Instead, ridges comprise many short segments slightly offset from one another. The offsets are a special kind of fault, or break in the lithosphere, known as a transform fault, and their function is to connect segments of a spreading ridge. The opposite sides of a transform fault belong to two different plates that are grinding against each other in opposite directions.

Transform faults form the boundaries that allow the plates to move relative to each another. The classic case of a transform boundary is the San Andreas Fault. It slices off a small piece of western California, which rides on the Pacific plate, from the rest of the state, which resides on the North American plate. As the two plates scrape past each other, stress builds up, eventually being released in earthquakes that can be quite violent.

Mantle Plumes and Hot Spots. Most plate tectonic features are near plate boundaries, but the Hawaiian Islands are not. In the late twentieth century, the only active volcanoes in the Hawaiian Islands were on the island of Hawaii, at the southeast end of the chain. Radiometric dating and examination of states of erosion show that, when proceeding along the chain to the northwest, successive islands are progressively older.

Evidently, the same heat source produced all the volcanoes in the Hawaiian chain. Known as a mantle plume, it has remained stationary while the Pacific plate rides over it, producing a volcanic trail from which absolute motion of the plate can be determined. Since mantle plumes do not move with the plates, the plumes must originate beneath the lithosphere,

Yellowstone is one of at least one hundred of Earth's hot spots where the heat source, known as a mantle plume, has remained stationary while the tectonic plate rode over it, producing volcanoes, geysers, and hot springs. (Digital Stock) probably far below it. Resulting volcanoes are called hot spots to distinguish them from subduction-zone volcanoes. Iceland is a good example of a hot spot, as is Yellowstone National Park in the United States. At least one hundred hot spots are distributed around Earth.

Alvin K. Benson

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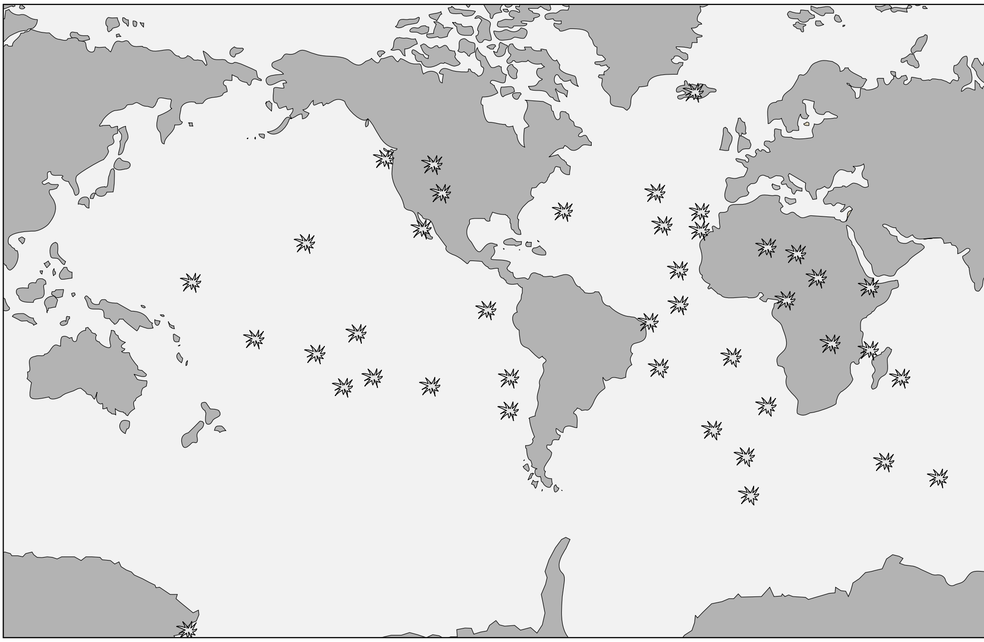
Volcanoes

Volcanoes form mountains both on land and in the sea and either do it on a grand scale or merely create minute bumps on the seafloor. Volcanoes do not occur in a random pattern, but are found in distinct zones that are related to plate dynamics. Each of the three types of volcanism on Earth is characterized by specific types of eruptions and magma compositions. Molten magma is the rock material below the earth's crust that forms igneous rock as it cools.

Types of Volcanoes. Abundant mid-ocean ridge basalt (MORB) volcanism occurs at divergent plate margins, where new ocean floor is created. The mid-Atlantic ridge is a submarine chain of such volcanoes, which emerges above the sea surface in Iceland.

The second type is the hot-spot or plume volcano, which is associated with mantle upwellings from great depth. When the plumes appear below an oceanic plate, large basaltic volcanoes (shield volcanoes) form, such as those on Hawaii and the Galapagos Islands. When the plume oc-

Some Volcanic Hot Spots Around the World



curs below a continent, wholesale melting of the crust may take place, creating a large volcanic area such as Yellowstone National Park in the United States.

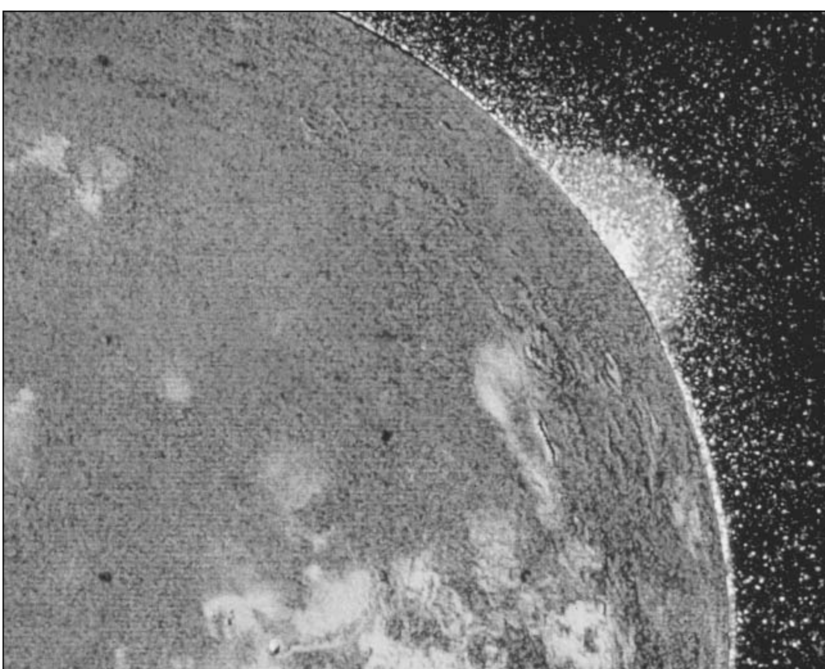
Arc volcanoes are found near subduction zones, in which oceanic plates are subducted below other oceanic plates (for example, the Aleutian Arc) or beneath continents, such as the Andes volcanoes. Some of the world's classical examples of cone-shaped stratovolcanoes, such as Mount Fuji in Japan, Mayon in the Philippines, and several Cascade Range volcanoes in Oregon and Washington, are arc volcanoes. Some of the highest volcanoes on Earth are of the arc type, notably Nevado Ojos del Salado (22,600 feet/6,885 meters) in the Chilean Andes.

A cross-section of the earth shows a subduction zone with associated arc volcanism and illustrates the trench and the volcanic arc. MORB volcanoes are shown where two plates are drifting apart, and plume volcanoes form tracks where the plume "burned through" the overriding plate.

Volcanic Composition. Volcanoes in the midocean ridges and plume environments draw most of their magmas from the earth's mantle and produce mainly dark, magnesium-rich basaltic magmas. When basaltic magmas accumulate in the continental crust (for example, at Yellowstone), the large-scale crustal melting leads to rhyolitic volcanism, the volcanic equivalent of granites. Arc magmas cover a wider range of magmatic compositions, ranging from arc basalt to light-colored, silica-rich rhyolites; the latter are commonly erupted in the form of the silica-rich volcanic rock known as pumice, or the black volcanic glass known as obsidian. Andesites, named after the Andes Mountains, are a common volcanic rock in arc volcanoes, intermediate in composition between basalt and rhyolite.

Magmas form from several processes that lead to partial melting of a solid rock. The simplest is adding heat—for example, plumes carrying heat from deep levels in the mantle to shallower levels, where melting occurs. Decompressional (lowering the pressure) melting of the mantle occurs where the ocean floor is thinned or carried away by seafloor spreading in midocean ridge environments.

Genesis of Magma. Adding a "flux" to a solid mineral mixture may lower the substance's melting point. The most common theory about arc magma genesis invokes the addition of a low-melting-point substance to the arc mantle, a layer of mantle material at about 60 to 90 miles (100 to 150 km.) below the volcanic arc. The relatively dry arc mantle would usually start to melt at about 2,100 to 2,300 degrees Fahrenheit (1,200 to 1,300 degrees Celsius). However, the addition of water and other gases



The fact that Earth is not the only body in Earth's solar system with active volcanoes is proven in this photograph of an volcanic eruption on Jupiter's moon Io. (PhotoDisc) can lower the melting point of the mixture. The water and its dissolved chemicals are supposedly derived from the subducted slab, the former ocean floor that is pushed back into the earth.

The sequence of events is as follows: New basaltic ocean floor forms at midocean ridge volcanoes. The new hot magma interacts with seawater, leading to vents at the seafloor with their mineralized deposits. The seafloor becomes hydrated, and sulfur and chlorine from seawater are locked up in newly formed minerals. During subduction, this altered seafloor with slivers of sediment, including limestone, is gradually warmed up and starts to decompose, adding a flux to the surrounding mantle rocks. The mantle rocks then start to melt, and these magmas with minor inherited oceanic materials start to rise and pond at the bottom of the crust. There the magmas sit and wait for an opportunity to erupt, while cooling and crystallizing. Thus, arc magmas bear a chemical signature of subducted oceanic components while their chemical compositions range from basalt to rhyolite.

Volcanic Eruptions. Volcanic eruptions occur as a result of the rise of magma into the volcano (from depths as great as several miles) and then into the throat of the volcano. In basaltic volcanoes, the magmas have relatively little gas, and the magma simply overflows and forms large lava flows, sometimes associated with fire fountains. Arc volcanoes can erupt regularly with small explosions or catastrophically after long periods of

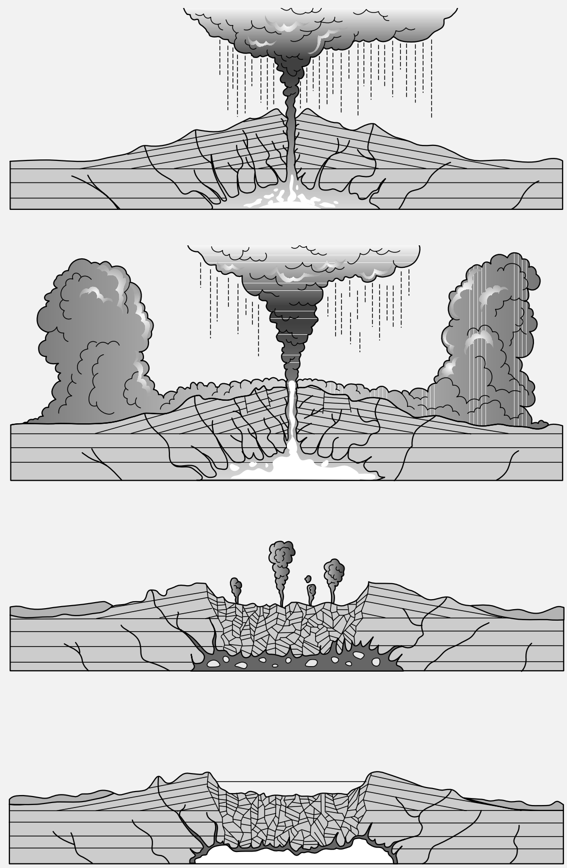
Destruction caused by the eruption of Mount St. Helens in 1980. The eruption knocked down thousands of acres of trees and spewed more than three cubic miles of material into the atmosphere. (Corbis)

Forest flattened by a volcanic eruption. (PhotoDisc)

dormancy. Mount Stromboli, a volcano in Italy, erupts every twenty minutes, with an explosion that creates a column 650 to 980 feet (200 to 300 meters) high. Mount St. Helens in the U.S. state of Washington had a catastrophic eruption in 1980 after about two hundred years of dormancy. It emitted an ash plume that reached more than 12 miles (20 km.) into the atmosphere.

After long magma storage periods in the crust, crystallization and melting of crustal material can lead to silica-rich magmas. These are viscous and can have high dissolved water contents—up to 4 to 6 percent by weight. When these magmas break out, the eruption can be violent and form an eruption column 12 to 35 miles (20 to 55 km.) high. Many cubic

Volcanic Eruption and Caldera Formation



miles of magma can be ejected. This leads to so-called plinian ash falls, with showers of pumice and ash over thousands of square miles, with the ash commonly carried around the globe by the high-level winds known as jet streams.

If the volume of ejected magma is large, the volcano empties itself and collapses into the hole, leading to a caldera—a volcanic collapse structure. The caldera at Crater Lake in Oregon is related to a large pumice eruption about 76,000 years ago. Basaltic volcanoes can also form collapse calderas when large volumes of lava have been extruded in a short time. Examples of famous basaltic calderas can be found in Hawaii's Mount Kilauea and the Galapagos Islands.

The caldera of Oregon's Crater Lake owes its origins to a large pumice eruption that occurred about 76,000 years ago, when the large volume of ejected matter caused the volcano to empty itself and collapse into the hole. (PhotoDisc)

Volcanic Plumes. The dynamics of volcanic plumes have been studied from eruption photographs, experiments, and theoretical work. The rapidly expanding hot gases force the viscous magma out of the throat of the volcano, where it freezes into pumice. The kinetic energy of the ejected mass carries it 2 to 2.5 miles (3-4 km.) above the volcano. During this phase, air is entrained in the column, diluting the concentration of ash and pumice particles. The hot particles heat the entrained air, the mixture of hot air and solids becomes less dense than the surrounding atmosphere, and a buoyant column rises high into the sky.

The height of an eruption column is not directly proportional to the force of the eruption but is strongly dependent on the rate of heat release of the volcano. If little of the entrained air is heated up, the column will collapse back to the ground and an ash flow forms, which may deposit ash around the volcano. These types of eruptions are among the most devastating, creating glowing ash clouds traveling at speeds up to 60 miles (100 km.) per hour, burning everything in their path. The 1902 eruption of Mount Pelée on Martinique in the Caribbean was such an eruption and killed nearly thirty thousand people in a few minutes.

Many volcanoes that are high in elevation are glaciated, and their eruptions lead to large-scale ice melting and possible mixing of water, magma, and volcanic debris. Massive hot mudflows can race down from the volcano, following river valleys and filling up low areas. The 1980 Mount St. Helens eruption created many mudflows, some of which reached the Pacific Ocean, ninety miles to the west. A catastrophic mudflow event occurred in 1984 at Nevado del Ruiz, a volcano in Colombia, where twenty thousand people were buried in mud and perished. When magma intrudes under the ice, meltwater can accumulate and then escape catastrophically, but such meltwater bursts are rare outside Iceland.

Minerals and Gases in Eruptions. The gas-rich character of arc magmas leads to fluid escape at various levels in the volcanoes, and these fluids tend to be rich in chlorine. They can transport metals such as copper, lead, zinc, and gold at high concentrations, and lead to the enrichment of these metals in the fractured volcanic rocks. Many of the world's largest copper ore deposits are associated with older arc volcanism, where erosion has removed most of the volcanic structure and laid the volcano innards bare. Many active volcanoes have modern hydrothermal (hot-water) systems, leading to acid hot springs and crater lakes and the poten-

Eruption of Alaska's Crater Peak volcano in 1992.

tial to harness geothermal energy. Some areas in Japan, New Zealand, and Central America have an abundance of geothermal energy resources, which are gradually being developed.

Apart from the dangers of eruptions, continuous emissions of large amounts of sulfur dioxide, hydrochloric acid, and hydrofluoric acid present a danger of air pollution and acid rain. Incidences of emphysema and other irritations of the respiratory system are common in people living on the slopes of active volcanoes. The large lava emissions in Iceland in the eighteenth century led to acid fogs all over Europe. Many cattle died in Iceland during this period from the hydrofluoric acid vapors. High levels of fluorine in drinking water can lead to fluorosis, a disease that attacks the bone structure. The discharge of highly acidic fluids from hot springs and crater lakes can cause widespread environmental contamination, which can present a danger for crops gathered from fields irrigated with these waters and for local ecosystems in general.

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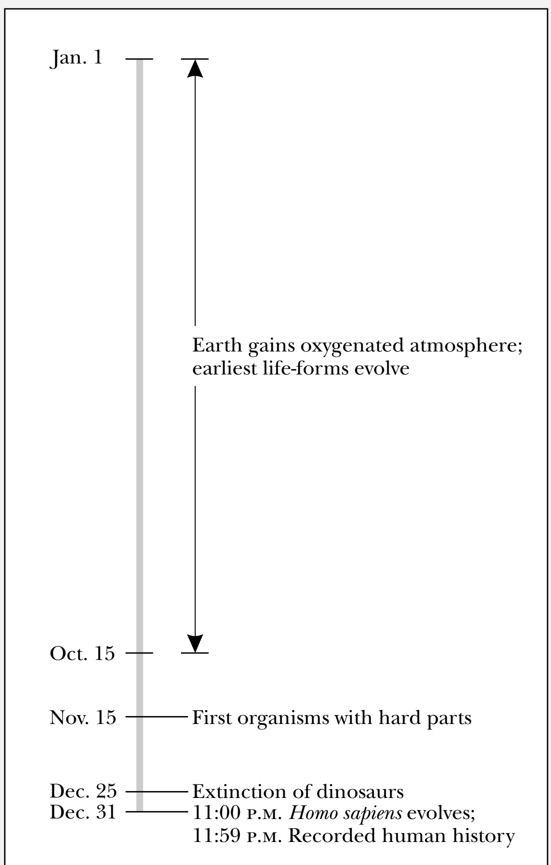
Geologic Time Scale

A major difference between the geosciences (earth sciences) and other sciences is the great enormity of their time scale. One might compare the magnitude of geologic time for geoscientists to the vastness of space for astronomers. Every geological process, such as the movement of crustal plates (plate tectonics), the formation of mountains, and the advance and retreat of glaciers, must be considered within the context of time.

Earth's History Compressed into One Calendar Year

One way to visualize events in Earth's history is to compress geologic events into a single calendar year. Earth's birth, 4.6 billion years ago, would occur during the first minute of January 1. The first three-quarters of Earth's history is obscure and would take place from January to mid-October. During this time, Earth gained an oxygenated atmosphere, and the earliest life-forms evolved. The first organisms with hard parts preserved in the fossil record (approximately 570 million years ago) would appear around November 15. The extinction of the dinosaurs (65 million years ago) would occur on Christmas Day. *Homo sapiens* would first appear at approximately 11 P.M. on December 31, and all of recorded human history would occur in the last few seconds of New Year's Eve.



Although certain geologic events, such as floods and earthquakes, seem to occur over short periods of time, the vast majority of observed geological features formed over a great span of time. Consequently, modern geoscientists consider Earth to be exceedingly old. Using radiometric age-dating techniques, they calculate the age of Earth as 4.6 billion years old.

Early miners were probably the first to recognize the need for a scale by which rock and mineral units could be compared over large geographic areas. However, before a time scale—and even geology as a science—could develop, certain principles had to be established. This did not occur until the late eighteenth century when James Hutton, a Scottish naturalist, began his extensive examinations of rock relationships and natural processes at work on the earth. His work was amplified by Charles Lyell in his textbook *Principles of Geology* (1830-1833). After careful observation, Hutton concluded that the natural processes and functions he observed had operated in the same basic manner in the past, and that, in general, natural laws were invariable. That idea became known as the principle of uniformitarianism.

The Birth of Stratigraphy. In 1669 Nicholas Steno, a Danish physician working in Italy, recognized that horizontal rock layers contained a chronological record of Earth history and formulated three important principles for interpreting that history. The principle of superposition states that in a succession of undeformed strata, the oldest stratum lies at the bottom, with successively younger ones above. The principle of original horizontality states that because sedimentary particles settle from fluids under graviational influence, sedimentary rock layers must be horizontal; if not, they have suffered from subsequent disturbance. The principle of original lateral continuity states that strata originally extended in all directions until they thinned to zero or terminated against the edges of the original area of deposition.

In the late eighteenth century, the English surveyor William Smith recognized the wide geographic uniformity of rock layers and discovered the utility of fossils in correlating these layers. By 1815, Smith had com-

The stratigraphic layers of sandstone, mudstone, coal and shale found in the Drumheller Badlands of Alberta, Canada, are a rich source of dinosaur fossils and skeletons, and they help scientists attach dates to geologic events. (Digital Stock)

Zion National Park. The walls of Zion Canyon, cut by the Virgin River, reveal fossils and other traces of the geologic past, going back as early as the Mesozoic Era. (PhotoDisc)

pleted a geologic map of England and was able to correlate English rock layers with layers exposed across the English Channel in France.

From the need to classify and organize rock layers into an orderly form arose a subdiscipline of modern geology—stratigraphy, the study of rock layers and their age relationships. In 1835 two British geologists, Adam Sedgwick and Roderick Murchison, began organizing rock units into a formal stratigraphic classification. Large divisions, called eras, were based upon well-known and characteristic fossils, and included a number of smaller subdivisions, called periods.

The periods are often subdivided into smaller units called epochs. Each period is defined by a representative sequence of rock strata and fossils. For instance, the Devonian period is named for exposures of rock in Devonshire in southern England, while the Jurassic period is defined by strata exposed in the Jura Mountains in northern Switzerland.

Approximately 80 percent of Earth's history is included in the Cryptozoic era (meaning obscure life). Fossils from the Cryptozoic era are rare, and the rock record is very incomplete. After the Cryptozoic era came the Paleozoic (ancient life), Mesozoic (middle life), and Cenozoic (recent life) eras. Most of the life forms that evolved during the Paleozoic and Mesozoic eras are now extinct, whereas 90 percent of the life forms that evolved up to the middle Cenozoic era still exist.

The Geologic Time Scale. The geologic time scale is continually in revision as new rock formations are discovered and dated. The ages shown in the table below are in millions of years ago (MYA) before the present and represent the beginning of that particular period. It would be impossible to list all the significant events in Earth's history, but one or two are provided for each period. Note that in the United States, the Carboniferous period has been subdivided into the Mississippian period (older) and the Pennsylvanian period (younger).

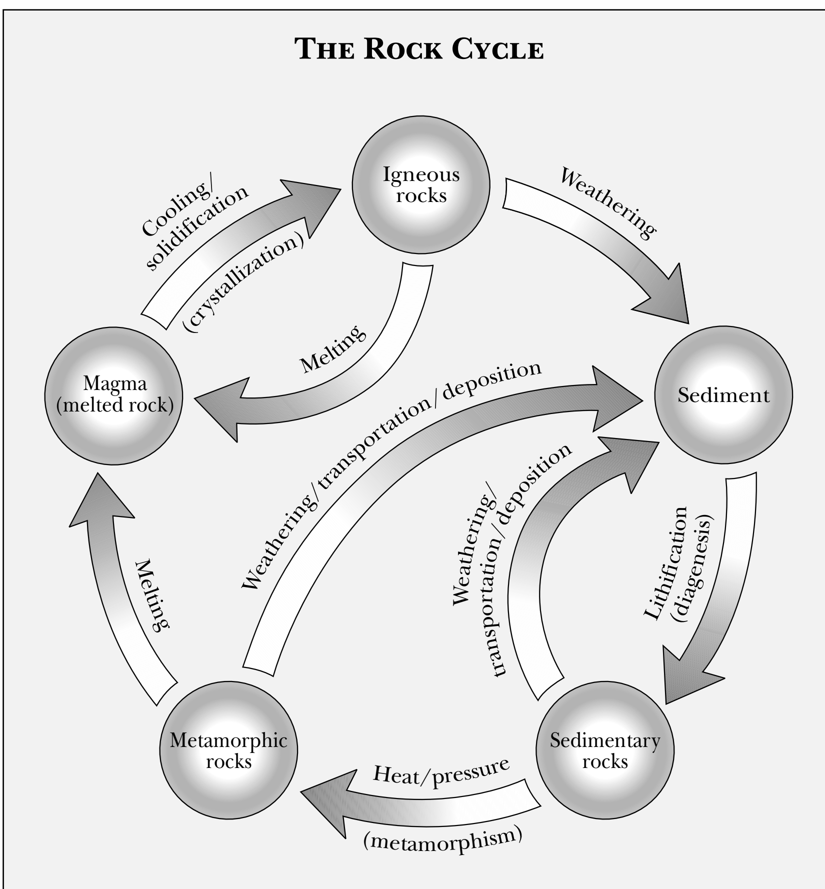
The Fossil Record. The word "fossil" comes from the Latin *fossilium*, meaning "dug from beneath the surface of the ground." Fossils are defined as any physical evidence of past life. Fossils can include not only shells, bones, and teeth, but also tracks, trails, and burrows. The latter group are referred to as trace fossils. Fossils demonstrate two important truths about life on Earth: First, thousands of species of plants and animals have existed and later became extinct. Second, plants and animals have evolved through time, and the communities of life that have existed on Earth have changed.

Some organisms are slow to evolve and may exist in several geologic time periods, while others evolve quickly and are restricted to small intervals of time within a particular period. The latter, referred to as index fossils, are the most useful to geoscientists for correlating rock layers over wide geographic areas and for recognizing geologic time.

The fossil record is incomplete, because the process of preservation favors organisms with hard parts that are rapidly buried by sediments soon

Fossil leaves from sandstone of the Gerome Andesite, Northwest Uranium Mine, Stevens County, Washington. (U.S. Geological Survey) after death. For this reason, the vast majority of fossils are represented by marine invertebrates with exoskeletons, such as clams and snails. Under special circumstances, soft-bodied organisms can be preserved, for instance the preservation of insects in amber, made famous by the feature film *Jurassic Park* (1993).

The Rock Cycle. A rock is a naturally formed aggregate of one or more minerals. Three types of rocks exist in the earth's crust, each reflecting a different origin. Igneous rocks have cooled and solidified from molten material either at or beneath Earth's surface. Sedimentary rocks form when preexisting rocks are weathered and broken down into fragments that accumulate and become compacted or cemented together. Fossils are most commonly found in sedimentary rocks. Metamorphic rocks form when heat, pressure, or chemical reactions in Earth's interior change the mineral or chemical composition and structure of any type of preexisting rock.



Over the huge span of geologic time, rocks of any one of these basic types can change into either of the other types or into a different form of the same type. For this reason, older rocks become increasingly more rare. The processes by which the various rock types change over time are illustrated in the rock cycle.

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Geologic Time: Online Edition, a Web site maintained by the U.S. Geological Survey, contains links to a wide range of topics, including the geologic time scale, index fossils, and radiometric dating. (pubs.usgs.gov/gip/geotime/)

The Web site of the Geological Society of America, headquartered in Boulder, Colorado, features information about current issues, publications, and careers in Earth science. (www.geosociety.org)

The Museum of Paleontology of the University of California at Berkeley, maintains a Web site with on-line exhibits on the history of life, geologic time periods, and fossils. (www.ucmp.berkeley.edu/index.html)

Earth's Surface

Internal Geological Processes

The earth is layered into a core, a mantle, and a crust. The topmost mantle and the crust make up the lithosphere. Beneath this is a layer called the asthenosphere, which is composed of moldable and partly liquid materials. Heat transference within the asthenosphere sets up convection cells that diverge from hot regions and converge to cold regions. Consequently, the overlying lithosphere is segmented into ridged plates that are moved by the convection process. The hot asthenosphere does not rise along a line. This causes the development of a structure called a transform plate boundary, which is perpendicular to and offsetting the divergent boundary.

The topographic features at Earth's surface, such as mountains, rift valleys, oceans, islands, and ocean trenches, are produced by extension or compression forces that act along divergent, convergent, or transform plate boundaries. The extension and compression forces at Earth's surface are powered by convection within the asthenosphere.

Mountains and Depressions in Zones of Compression. Compression along convergent plate boundaries yields three types of mountain: island arcs that are partly under water; mountains along a continental edge, such as the Andes; and mountains at continental interiors, such as the Alps. At convergent plate boundaries, the denser of the two colliding plates slides down into the asthenosphere and causes volcanic activity to form on the leading edge of the upper plate. Island arcs such as the Aleutians and the Caribbean are formed when an oceanic plate descends beneath another oceanic plate.

Volcanic mountain chains such as the Andes of South America are formed when an oceanic plate descends beneath a continental plate. In both the island arc type and Andean type collisions, a deep depression in the oceans, called a trench, marks the place where neighboring plates are colliding and where the denser plates are pulled downward into the asthenosphere. If the colliding plates are of similar density, neither plate will go into the asthenosphere. Instead, the edges of the neighboring plates will be folded and faulted and excess material will be pushed upward to form a block mountain, such as the mountain chain that stretches from the Alps through to the Himalayas. This type of mountain chain is not associated with a trench.

The Appalachians of the eastern United States are an example of the alpine type of mountain belt. When the Appalachians were forming 300 million years ago, rock layers were deformed. The deformation included folding to form ridges and valleys; fracturing along joint sets, with one joint set being parallel to ridges, while the other set is perpendicular; and thrust faulting, in which rock blocks were detached and shoved upward and northwestward.

Millions of years of erosion have reduced the height of the mountains and have produced topographic inversion in the foothills. Topographic inversion occurs because joints create wider fractures at upfolded ridges and narrower fractures at downfolded valleys. Erosion is then accelerated at upfolded ridges, converting ancient ridges into valleys, while ancient valleys stand as ridges. The Valley and Ridge Province of the Appalachians is noted for such topographic inversion.

West of the Valley and Ridge Province of the Appalachians is the Allegheny Plateau, which is bounded by a cliff on its eastern side. In general, plateaus are flat topped because the rock layer that covers the surface is resistant to weathering. The cliff side is formed by erosion along joint or fault surfaces.

The Sierra Nevada range, which formed seventy million years ago, is an example of an Andean type of mountain belt. Millions of years of erosion there has exposed igneous rocks that formed at depth. Over the years, the force of compression that formed the Sierras has evolved to form a zone of extension between the Sierras and the Colorado Plateau.

Mountains and Depressions in Zones of Extension. Extension is a strain that involves an increase in length and causes crustal thinning and faulting. Extension is associated with convergent boundaries, divergent boundaries, and transform boundaries.

Extension Associated with a Convergent Boundary. During the formation of the Sierra Nevada, an oceanic plate that was subducted beneath California declined at a shallow angle eastward toward the Colorado Plateau. Later, the subducted plate peeled off and molten asthenosphere took its place. From the asthenosphere, lava ascended through fractures to form volcanic mountains in Arizona and Utah, and lava flowed and volcanic ash fell as far west as California. The lithosphere has been heated up and has become buoyant, so the Colorado Plateau rises to higher elevations, and rock layers slide westward from it in a zone of extension that characterizes the Basin and Range Province.

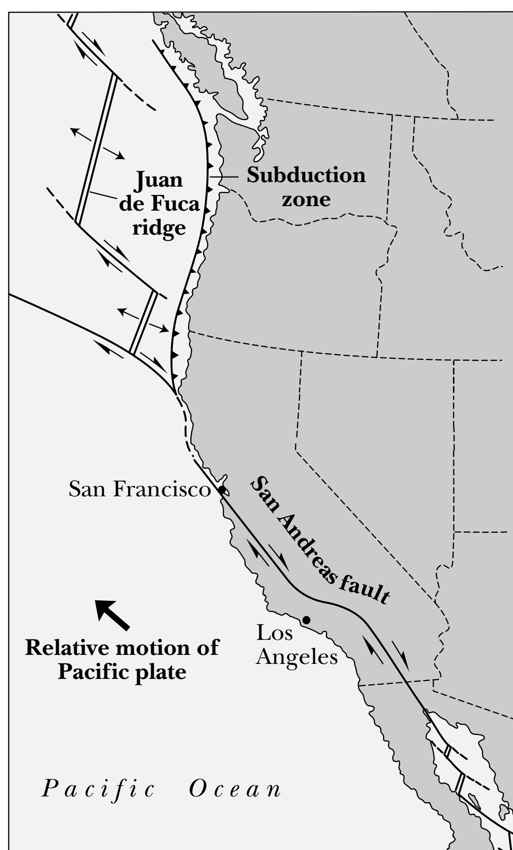
In the extension zone, the top rock layers move westward on curved displacement planes that are steep at the surface and nearly horizontal at depth. When rock layers move westward over a curved detachment surface, the trailing edges of the rock layers roll over and are tilted toward the east so they do not leave space in buried rocks. On the other hand, a west-facing slope is left behind on a mountain from which the rock layers were detached. Therefore, movement along one curved detachment surface creates a valley, and movement along several such detachment surfaces forms a series of valleys separated by ridges, as in the Basin and Range Province. The amount of the displacement along the curved surfaces is not uniform. For example, more displacement has created wide zones of valleys such as the Las Vegas valley in Nevada, and Death Valley in California.

Extension Associated with a Divergent Boundary. The longest mountain chain on Earth lies under the Pacific Ocean. It is about 37,500 miles (60,000 km.) long, 31.3 miles (50 km.) wide, and 2 miles (3 km.) high. The central part of this midoceanic ridge is marked by a depression, about 3,000 feet (1,000 meters) deep, and is called a rift valley. A part of the submarine ridge, called the East Pacific Rise, forms the seafloor sector in the Gulf of California and reappears off the coast of northern California, Oregon, and Washington as the Juan de Fuca Ridge. Another part forms the seafloor sector in the Gulf of Aden and Red Sea seafloor, part of which is exposed in the Afar of Ethiopia. From the Afar southward to the southern part of Mozambique is the longest exposed rift valley on land, the East African Great Rift Valley.

A rift valley is the place where old rocks are pushed aside and new rocks are created. Blocks of rock that are detached from the rift walls slide down by a series of normal fault displacements. The ridge adjacent to the central rift is present because hot rocks are less dense and buoyant. If the process of divergences continues from the rifting stage to a drifting stage, as the rocks move farther away from the central rift, the rocks become older, colder, and denser, and push on the underlying asthenosphere to create basins. These basins will be flooded by oceanic water as neighboring continents drift away. However, not all processes of divergence advance from the rifting to the drifting stage.

Extension Associated with Transform Boundary. The best-known example of a transform boundary is the San Andreas Fault that offsets the East Pacific Rise from the Juan de Fuca Ridge, and is exposed on land from the Gulf of California to San Francisco. Along transform boundaries, there are pull-

California's San Andreas Fault



apart basins that may be filled to form lakes, such as the Salton Sea in Southern California. Another example is the Aqaba transform of the Middle East, along which the Sea of Galilee and the Dead Sea are located.

H. G. Churnet

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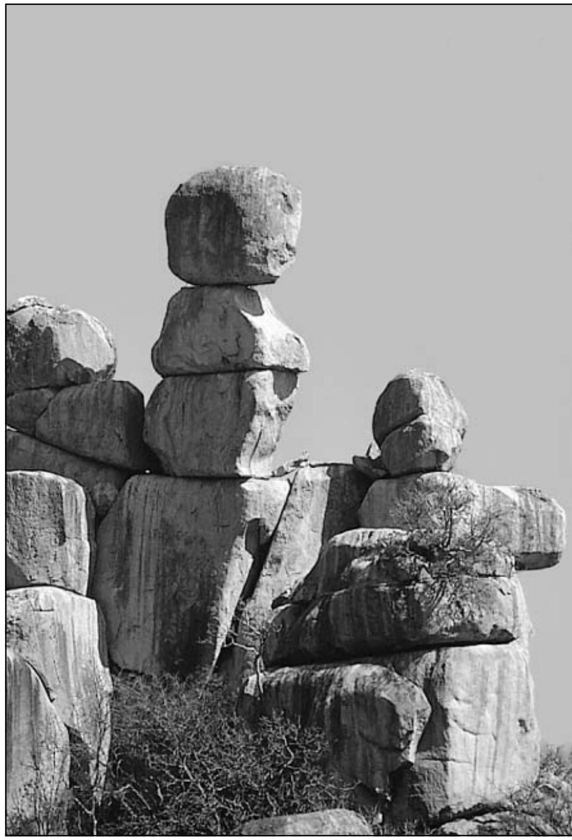
External Processes

Continuous processes are at work shaping the earth's surface. These include breaking down rocks, moving the pieces, and depositing the pieces in new locations. Weathering is the breaking down of rocks through atmospheric agents. The process of moving weathered pieces of rock by wind, water, ice, or gravity is called erosion. The materials that are deposited by erosion are called sediment.

Mechanical weathering occurs when a rock is broken into smaller pieces but its chemical makeup is not changed. If the rock is broken down by a change in its chemical composition, the process is called chemical weathering.

Mechanical Weathering. Different types of mechanical weathering occur, depending on climatic conditions. In areas with moist climates and fluctuating temperatures, rocks can be broken apart by frost wedging. Water fills in cracks in rocks, then freezes during cold nights. As the ice expands and pushes out on the crack walls, the crack enlarges. During the warm days, the water thaws and flows deeper into the enlarged crack.



In climates with fluctuating temperatures, unusual rock formations such as these granite piles in Zimbabwe's Matopo Hills, are typically the products of mechanical weathering. (R. Kent Rasmussen)

Over time, the crack grows until the rock is broken apart. This process is active in mountains, producing a pile of rock pieces at the mountain base called talus.

Salt weathering occurs in areas where much salt is available or there is a high evaporation rate, such as along the seashore. Salt crystals form when salty moisture enters rock cracks. Growing crystals settle in the bottom of the crack and apply pressure on the crack walls, enlarging the crack.

Thermal expansion and contraction occur in climates with fluctuating temperatures, such as deserts. All minerals expand during hot days and contract during cold nights, and some minerals expand and contract more than others. This process continues until the rock loosens up and breaks into pieces.

Mechanical exfoliation can happen to a rock body overlain by a thick rock or sediment layer. If the heavy overlying layer over a portion of the rock body is removed, pressure is relieved and the exposed rock surface will expand in response. This expanding surface will break off into sheets parallel to the surface, but the remaining rock body remains under pressure and unchanged.

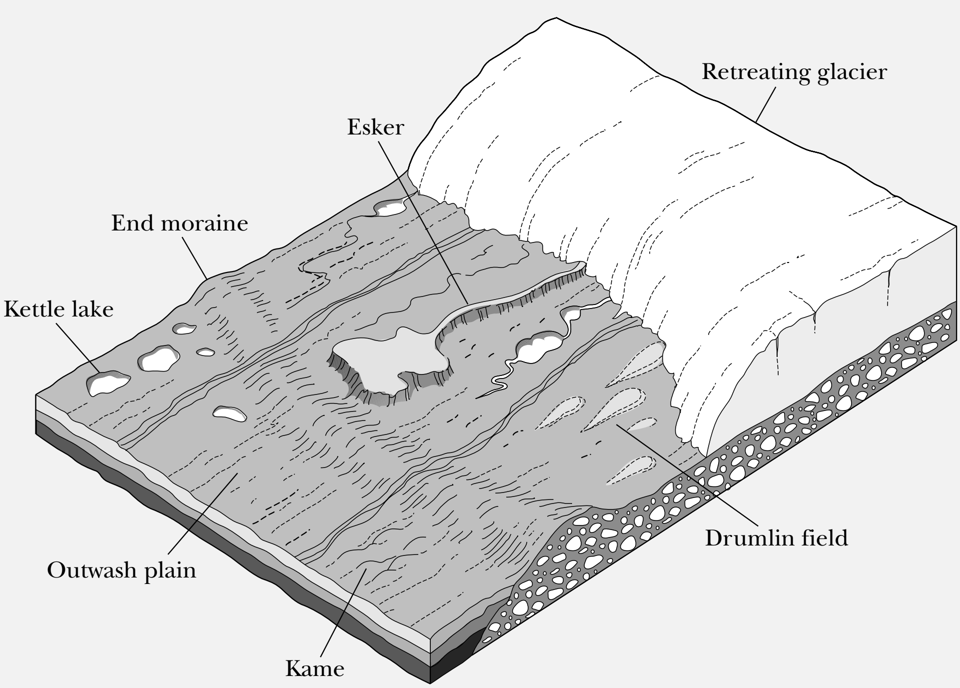
When plant roots grow into cracks in rocks, they enlarge the cracks and break up the rocks. Finally, abrasion can occur to rock fragments during transport. Either the fragments collide, breaking apart, or fragments are scraped against rocks, breaking off pieces.

Chemical Weathering. Water and oxygen create two common causes of chemical weathering. For example, dissolution occurs when water or another solution dissolves minerals within a rock and carries them away. Hydrolysis can occur when water flows through earth materials. The hydrogen ions or the hydroxide ions of the water may react with minerals in the rocks. When this occurs, the chemical composition of the mineral is changed, and a new mineral is formed. Hydrolysis often produces clay minerals.

Some elements in minerals combine with oxygen from the atmosphere, creating a new mineral. This process is called oxidation. Some of these oxidation minerals are commonly referred to as rust.

Mass Movement. Weathered rock pieces (sediments) are transported (eroded) by one or more of four transport processes: water (streams and oceans), wind, ice (glaciers), or gravity. Mass movement transports earth

Depositional Landforms Left by a Glacier



materials down slopes by the pull of gravity. Gravity, constantly working to pull surface materials down, parallel to the slope, is the most important factor affecting mass movement. There is also a force involved perpendicular to the slope that contributes to the effects of friction.

Friction, the second factor, is determined by the earth material type involved. For example, weathering may create cracks in rocks, which form planes of weakness on which the mass movement can occur. Loose sediments always tend to roll downhill.

The third factor is the slope angle. Each earth material has its own angle of repose, which is the steepest slope angle on which the materials remain stable. Beyond this slope angle, earth materials will move downslope.

Water, the fourth factor, affects the stability of the earth material in the slope. Friction is weakened by water between the mineral grains in the rock. For example, water can make clay quite slippery, causing the mass movement.

The rooting system of vegetation, the fifth factor, helps make the surficial materials of the slope stable by binding the loose materials together.

Mass movements can be classified by their speed of movement. Creep and solifluction are the two types of slow mass movement, which are measured in fractions of inches per year. Creep is the slowest mass movement process, where unconsolidated materials at the surface of a slope move slowly downslope. The materials move slightly faster at the surface than below, so evidence of creep commonly can be seen by slanted telephone poles. During solifluction, the warm sun of the brief summer season in cold regions thaws the upper few feet of the earth. This waterlogged soil flows downslope over the underlying permafrost.

Rapid mass movement processes occur at feet per second or miles per hour. Falls occur when loose rock or sediment is dislodged and drops from a steep slope, such as along sea cliffs where waves erode the cliff base. Topples occur when there is an overturning movement of the mass. A topple can turn into a fall or a slide. A slide is a mass of rock or sediment that becomes dislodged and moves along a plane of weakness, such as a fracture. A slump is a slide that separates along a concave surface. Lateral spreads occur when a fractured earth mass spreads out at the sides.

A flow occurs when a mass of wet or dry rock fragments or sediment moves downslope as a highly viscous fluid. There are several different flow types. A debris flow is a mass of relatively dry, broken pieces of earth material that suddenly has water added. The debris flow occurs on steeper slopes and moves at speeds of 1-25 miles (2-40 km.) per hour. A debris avalanche occurs when an entire area of soil and underlying weathered bedrock becomes detached from the underlying bedrock and moves quickly down the slope. This flow type is often triggered by heavy rains in areas where vegetation has been removed. An earthflow is a dry mass of clayey or silty material that moves relatively slowly down the slope. A mudflow is a mass of earth material mixed with water that moves quickly down the slope.

A quick clay can occur when partially saturated, solid, clayey sediments are subjected to an earthquake, explosion, or loud noise and become liquid instantly.

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Information on North American geology can be found through the American Geological Institute. (www.agiweb.org)

Fluvial and Karst Processes

Earth's landscape has been sculptured into an almost infinite variety of forms. The earth's surface has been modified by various processes for thousands, even hundreds of millions, of years to arrive at the modern configuration of landscapes.

Each process that transforms the surface is classified as either endogenic or exogenic. Endogenic processes are driven by the earth's internal heat and energy and are responsible for major crustal deformation. Endogenic processes are considered constructional, because they build up the earth's surface and create new landforms, such as mountain systems. Conversely, exogenic processes are considered destructional be-

How Hydrology Shapes Geography

Water and ice sculpt the landscape over time. Fast-flowing rivers erode the soil and rock through which they flow. When rivers slow down in flatter areas, they deposit eroded sediments, creating areas of rich soils and deltas at the mouths of the rivers. Over time this process wears down mountain ranges. The Appalachian Mountain range on the eastern side of the North American continent is hundreds of millions of years older than the Rocky Mountain range on the continent's western side. Although the Appalachians once rivaled the Rockies in size, they have been made smaller by time and erosion.

Canyons are carved by rivers, as the Grand Canyon was carved by the Colorado River, which exposed rocks billions of years old. Ice also changes the landscape. Large ice sheets from past ice ages could have been well over a mile (1,600 meters) thick, and they scoured enormous amounts of soil and rock as they slowly moved over the land surface. Terminal moraines are the enormous mounds of soil pushed directly in front of the ice sheets. Long Island, New York, and Cape Cod, Massachusetts, are two examples of enormous terminal moraines that were left behind when the ice sheets retreated.

cause they result in the wearing away of landforms created by endogenic processes. Exogenic processes are driven by solar energy putting into motion the earth's atmosphere and water, resulting in the lowering of features originally created by endogenic processes.

The most effective exogenic processes for wearing away the landscape are those that involve the action of flowing water, commonly referred to as fluvial processes. Water flows over the surface as runoff, after it evaporates into the atmosphere and infiltrates into the soil. The water that is left over flows down under the influence of gravity and has tremendous energy for sculpturing the earth's surface. Although flowing water is the most effective agent for modifying the landscape, it represents less than 0.01 percent of all the water on Earth's surface. The oceans contain more than 97 percent of the earth's total volume of water.

Drainage Basins. Fluvial processes can be considered from a variety of spatial scales. The largest scale is the drainage basin. A drainage basin is the area defined by topographic divides that diverts all water and material within the basin to a single outlet. Every stream of any size has its own drainage basin, and every portion of the earth's land surfaces are located within a drainage basin. Drainage basins vary tremendously in size, depending on the size of the river considered. For example, the largest drainage basin on earth is the Amazon, which drains about 2.25 million square miles (5.83 million sq. km.) of South America.

The Amazon Basin is so large that it could contain nearly the entire continent of Australia. By comparison, the Mississippi River drainage basin, the largest in North America, drains an area of about 1,235,000 square miles (3,200,000 sq. km.). Smaller rivers have much smaller basins, with many draining only an area roughly the size of a football field. While basins vary tremendously in size, they are spatially organized, with larger basins receiving the drainage from smaller basins, and eventually draining into the ocean. Because drainage basins receive water and material from the landscape within the basin, they are sensitive to environmental change that occurs within the basin. For example, during the twentieth century, the Mississippi River was influenced by many human-imposed changes that occurred either within the basin or directly within the channel, such as agriculture, dams and reservoirs, and levees.

Drainage Networks and Surface Erosion. Drainage basins can be subdivided into drainage networks by the arrangement of their valleys and interfluves. Interfluves are the ridges of higher elevation that separate adjacent valleys. Where an interfluve represents a natural boundary between two or more basins, it is referred to as a drainage divide. Valleys contain the larger rivers and are easily distinguished from interfluves by their relatively low, flat surfaces. Interfluves have relatively steep slopes and, for this reason, are eroded by runoff. The term erosion refers to the transport of material, in this case sediment that is dislodged from the surface.

Runoff starts as a broad sheet of slow-moving water that is not very erosive. As it continues to flow downslope, it speeds up and concentrates into rills, which are narrow, fast-moving lines of water. Because the runoff is concentrated within rills, the water travels faster and has more energy for erosion. Thus, rills are responsible for transporting sediment from higher points of elevation within the basin to the valleys, which are at a lower elevation. Rills can become powerful enough to scour deeply into the surface, developing into permanent channels called gullies.

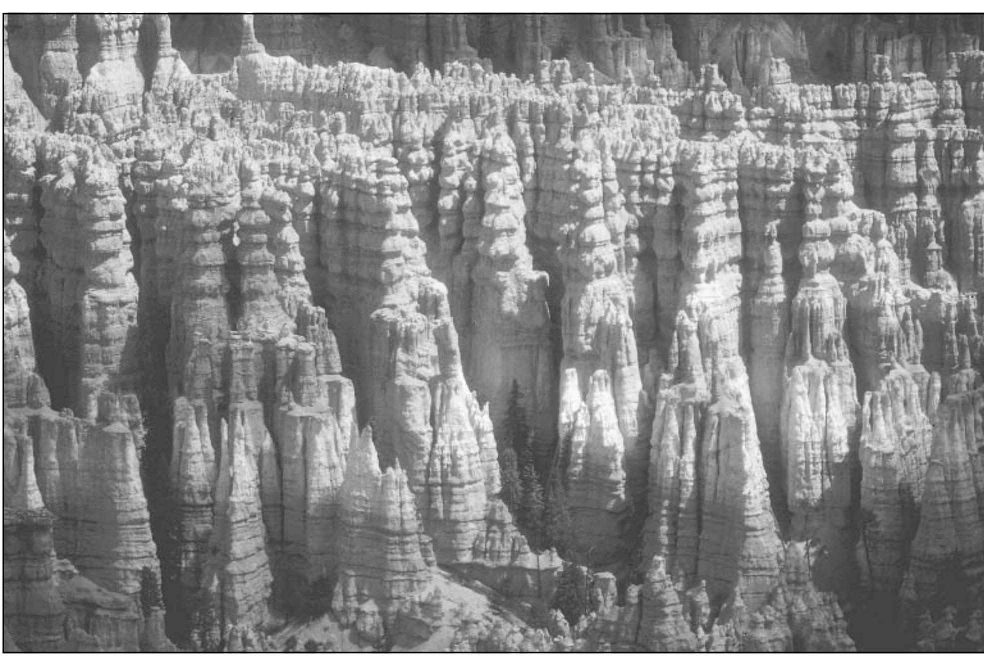
The presence of many gullies indicates significant erosion on the landscape and represents an expensive and long-lasting problem if it is not remedied after initial development. The formations of gullies is often associated with human manipulation of the earth. For example, gullies can develop after improper land management, particularly intensive agricultural and grazing practices. A change in land use from natural vegetation, such as forests or prairie, can result in a type of land cover that is not suited for preventing erosion. Such land surfaces become susceptible to the formation of gullies during heavy, prolonged rains.

At a smaller scale, fluvial processes can be considered from the perspective of the river channel. River channels are located within the valleys of basins, offering a permanent conduit for drainage. Higher in the basin, river channels and valleys are relatively narrow, but grow larger toward the mouth of the basin as they receive drainage from smaller rivers within the basin. River channels may be categorized by their planform pattern, which refers to their overhead appearance, such as would be viewed from the window of an airplane.

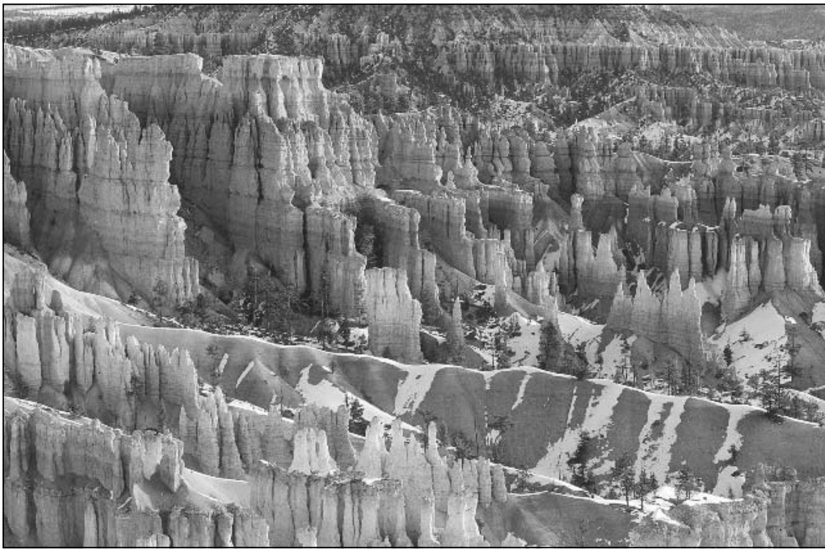
The two major types of rivers are meandering and braided. Meandering rivers have a single channel that is sinuous and winding. These rivers are characterized as having orderly and symmetrical bends, causing the river to alternate directions as it flows across its valley. In contrast, braided rivers contain numerous channels divided by small islands, which results in a disorganized pattern. The islands within a braided river channel are not permanent. Instead, they erode and form over the course of a few years, or even during large flood events. Meandering channels usually have narrow and deep channels, but braided river channels are shallow and wide.

Sediment and Floodplains. Another distinction between braided and meandering river channels is the types of sediment they transport. Braided rivers transport a great amount of sediment that is deposited into midchannel islands within the river. Also, because braided rivers are frequently located higher in the drainage basin, they may have larger sediments from the erosion of adjacent slopes. In contrast, meandering river channels are located closer to the mouth of the basin and transport fine-grained sediment that is easily stored within point bars, which results in symmetrical bends within the river.

The sediments of both meandering and braided rivers are deposited within the valleys onto floodplains. Floodplains are wide, flat surfaces



Utah's Bryce Canyon National Park was established in 1928 to preserve its oddly shaped and multicolored limestone cliffs and towers, which were created by karst processes. (Corbis)



Bryce Canyon in winter. (PhotoDisc)

formed from the accumulation of alluvium, which is a term for sediment that is deposited by water. Floodplain sediments are deposited with seasonal flooding. When a river floods, it transports a large amount of sediment from the channel to the adjacent floodplain. After the water escapes the channel, it loses energy and can no longer transport the sediment. As a result, the sediment falls out of suspension and is deposited onto the floodplain. Because flooding occurs seasonally, floodplain deposits are layered and may accumulate into very thick alluvial deposits over thousands of years.

Karst Processes and Landforms. A specialized type of exogenic process that is also related to the presence of water is karst. Karst processes and topography are characterized by the solution of limestone by acidic groundwater into a number of distinctive landforms. While fluvial processes lower the landscape from the surface, karst processes lower the landscape from beneath the surface. Because limestone is a very permeable sedimentary rock, it allows for a large amount of groundwater flow. The primary areas for solution of the limestone occur along bedding planes and joints. This creates a positive feedback by increasing the amount of water flowing through the rock, thereby further increasing solution of the limestone. The result is a complex maze of underground conduits and caverns, and a surface with few rivers because of the high degree of infiltration.

The surface topography of karst regions often is characterized as undulating. A closer inspection reveals numerous depressions that lack surface outlets. Where this is best developed, it is referred to as cockpit karst.

It occurs in areas underlain by extensive limestone and receiving high amounts of precipitation, for example, southern Illinois and Indiana in the midwestern United States, and in Puerto Rico and Jamaica.

Sinkholes are also common to karstic regions. Sinkholes are circular depressions having steep-sided vertical walls. Sinkholes can form either from the sudden collapse of the ceiling of an underground cavern or as a result of the gradual solution and lowering of the surface. Sinkholes can fill with sediments washed in from surface runoff. This reduces infiltration and results in the development of small circular lakes, particularly common in central Florida. Over time, erosion causes the vertical walls to retreat, resulting in uvalas, which are much larger flat-floored depressions.

Where there are numerous adjacent sinkholes, the retreat and expansion of the depressions causes them to coalesce, resulting in the formation of poljes. Unlike uvalas, poljes have an irregular shape, and the floor of the basin is not flat because of differences between the coalescing sinkholes.

Caves are among the most characteristic features of karst regions, but can only be seen beneath the surface. Caves can traverse the subsurface for miles, developing into a complex network of interconnected passages. Some caves develop spectacular formations as a result of the high amount of dissolved limestone transported by the groundwater. The evaporation of water results in the accumulation of carbonate deposits, which may grow for thousands of years. Some of the most common deposits are stalactites, which grow downward from the ceiling of the cave, and stalagmites, which grow upward and occasionally connect with stalactites to form large vertical columns.

Paul F. Hudson

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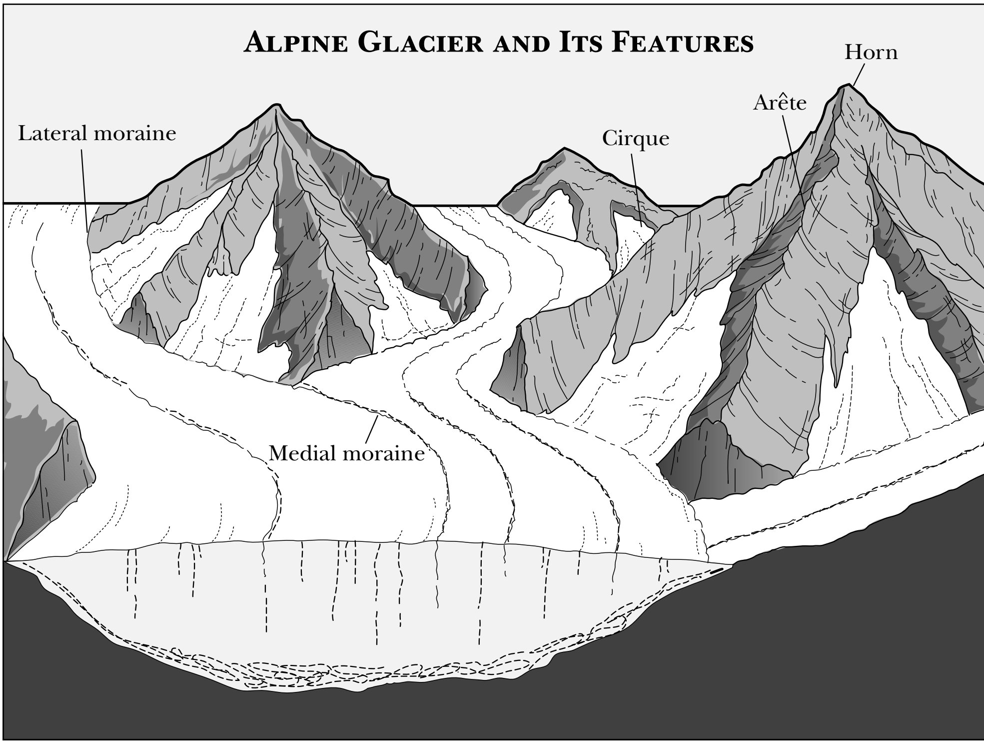
Glaciation

In areas where more snow accumulates each winter than can thaw in summer, glaciers form. Glacier ice, called firn, looks like rock but is not as strong as most rocks and is subject to intermittent thawing and freezing. Glacier ice can be brittle and fracture readily into crevasses, while other ice behaves as a plastic substance. A glacier is thickest in the area receiving the most snow, called the zone of accumulation. As the thickness piles up, it settles down and squeezes the limit of the ice outward in all directions. Eventually, the ice reaches a climate where the ice begins to melt and evaporate. This is called the zone of ablation.

Alpine Glaciation. Varied topographic evidence throughout the alpine environment attests to the sculpturing ability of glacial ice. The world's most spectacular mountain scenery has been produced by alpine glaciation, including the Matterhorn, Yosemite Valley, Glacier National Park, Mount Blanc, the Tetons, and Rocky Mountain National Park, all of

Nineteenth century engraving of Mont Blanc's Mer de Glace (Sea of Ice), a major tourist attraction in France both because it is the second-longest glacier in the Alps and because it seems alive, moving down the north slope of Mont Blanc at a rate of about 425 feet (130 meters) a year. (Mark Twain, *A Tramp Abroad*, 1880)

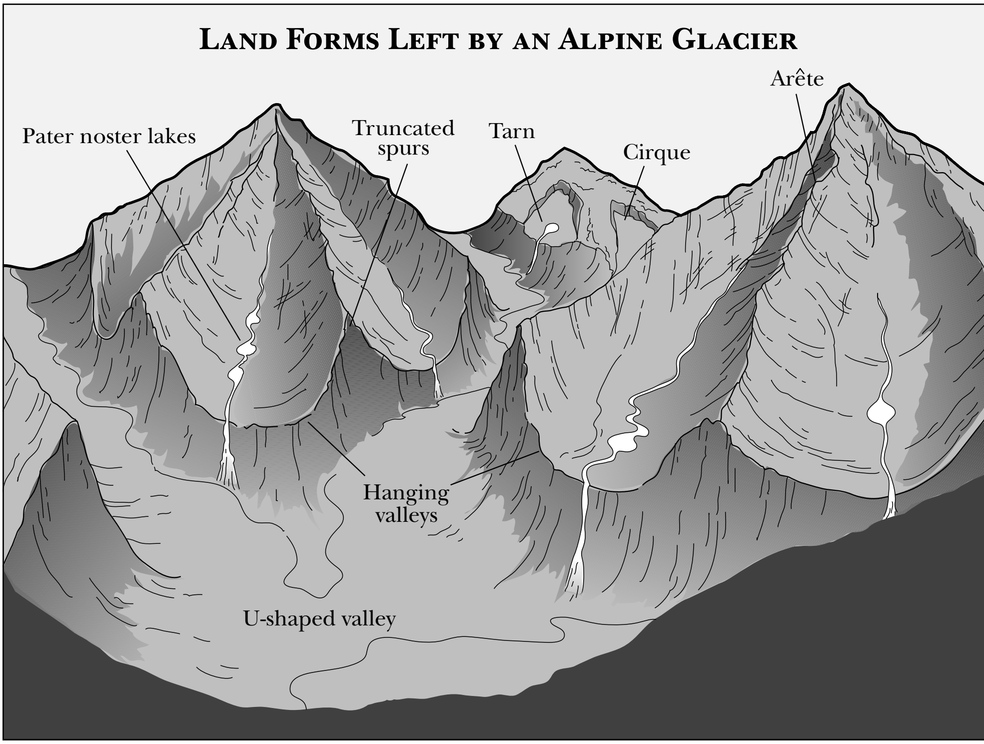


which are visited by large numbers of people annually. Although alpine glaciation is still an active process of land sculpture in the high mountain ranges of the world, it is much less active than it was in the Ice Age of the Pleistocene epoch.

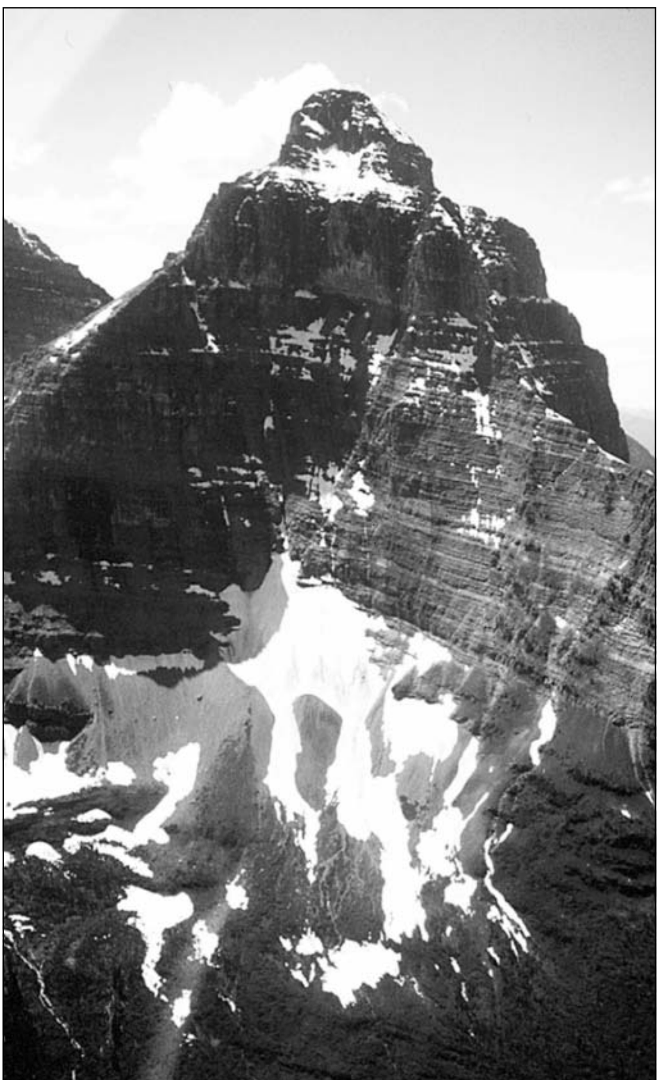
The prerequisites for alpine, or mountain, glaciation to become active are a mountainous terrain with Arctic climatic conditions in the higher elevations, and sufficient moisture to help snow and ice develop into glacial ice. As glaciers move out from their points of origin, they erode into the sides of mountains and increase the local relief in the higher elevations. The erosional features produced by alpine glaciation dominate mountain topography and usually are the most visible features on topographic maps. The eroded material is transported downvalley and deposited in a variety of landforms.

One kind of an erosional feature is a cirque, a hollow bowl-shaped depression. The bowl of the cirque commonly contains a small round lake or tarn. A steep-walled mountain ridge called an arête forms between two cirques. A high pyramidal peak, called a horn, is formed by the intersecting walls of three or more cirques.

Erosion is particularly rapid at the head of a glacier. In valleys, moving glaciers press rock fragments against the sides, widening and deepening



Alaska's Kennicott Glacier shows many landforms associated with glaciers, such as cirques, arêtes, and moraines. (PhotoDisc) them by abrasion and forming broad U-shaped valleys. When glaciers recede, tributary streams become higher than the floor of the U-shaped valley and waterfalls occur over these hanging valleys. As the ice continues to melt, residual sediments called moraines may be deposited. Moraines are made up of glacier till, a collection of sediment of all sizes. Bands of sediment along the side of a valley glacier are lateral moraines; those crossing the valley are end or recessional moraines; where two glaciers join, a medial moraine is formed. Meltwater may also sort out the finer materials, transport them downvalley, and deposit them in beds as outwash.



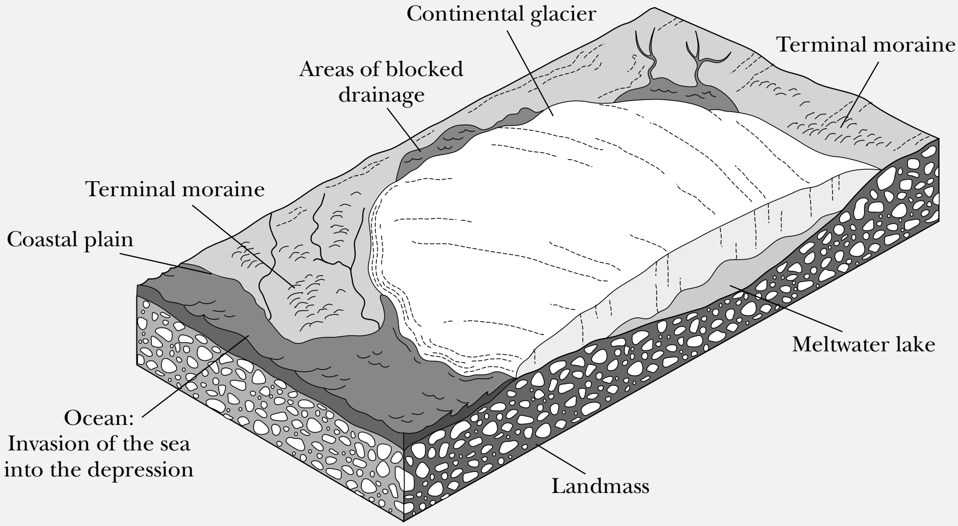
Kinnerly Peak, in Montana's Glacier National Park, is an example of a horn—a high pyramidal peak formed by the intersection of several cirques. (U.S. Geological Survey)

Glacier National Park has many examples of valleys carved by the movement of glaciers. (PhotoDisc)

Continental Glaciation. In the modern world, continental glaciation operates on a large scale only in Greenland and Antarctica. However, its existence in previous geologic ages is evidenced by strata of tillite (a compacted rock formed of glacial deposits) or, more frequently, by surficial deposits of glacial materials.

Much of the geomorphology of the northeastern quadrant of North America and the northwestern portion of Europe was formed during the Ice Age. During that time, great masses of ice accumulated on the continents and moved out from centers near the Hudson Bay and the Fenno-Scandian Shield, extending over the continents in great advancing and

Features of a Continental Glacier



retreating lobes. In North America, the four major stages of lobe advance were the Wisconsin (the most recent), the Illinoian, the Kansan, and the Nebraskan (the oldest). Between each of these major advances were pluvial periods in which the ice melted and great quantities of water rushed over or stood on the continents, creating distinctive features which can still be detected today.

The two major functions of gradation are accomplished by the processes of scour (degradation) in the areas close to the centers and deposi-

A Future Ice Age

If past geological history is an indicator, some time in the future conditions again will become favorable for the growth of glaciers. As recently as 1300 to 1600 C.E., a cold period known at the Little Ice Age settled over Northern Europe and Eastern North America. Viking colonies perished as agriculture became unfeasible, and previously ice-free rivers in Europe froze over.

Another ice age would probably develop rapidly and be impossible to stop. Active mountain glaciers would bury living forests. Great ice caps would again cover Europe and North America, moving at a rate of 100 feet (30 meters) per day. Major cities and populations would shift to the subtropics and the topics.

tion (aggradation) adjacent to the terminal or peripheral areas of the lobes. Thus, the overall effect of continental glaciation is to reduce relief—to scour high areas and fill in lower regions—unlike the changes caused by alpine glaciation.

Although continental glaciation usually does not result in the spectacular scenery of alpine glaciation, it was responsible for creating most of the Great Lakes and the lakes of Wisconsin, Michigan, Minnesota, Finland, and Canada; for gravel deposits; and for the rich agricultural lands of the Midwest, to mention just a few of its effects.

While glaciers were leveling hilly sections of North America and Europe by scraping them bare of soil and cutting into the ice itself, they acquired a tremendous load of material. As a glacier warms and melts, there is a tremendous outflow of water, and the streams thus formed carry with them the debris of the glacier. The material deposited by glaciers is called drift or outwash. Glaciofluvial drift can be recognized by its separation into layers of finer sands and coarser gravels.

Kettles and kames are the most common features of the end moraines found at the outermost edges of a glacier. A kettle is a depression left when a block of ice, partially or completely buried in deposits of drift, melts away. Most of the lakes in the upper Great Lakes of the United States are kettle lakes. A kame is a round, cone-shaped hill. Kames are produced by deposition from glacial meltwater. Sometimes, the outwash material poured into a long and deep crevasse, rather than a hole. These tunnels have had their courses choked by debris, revealed today by long, narrow ridges, generally referred to as eskers.

Ron Janke

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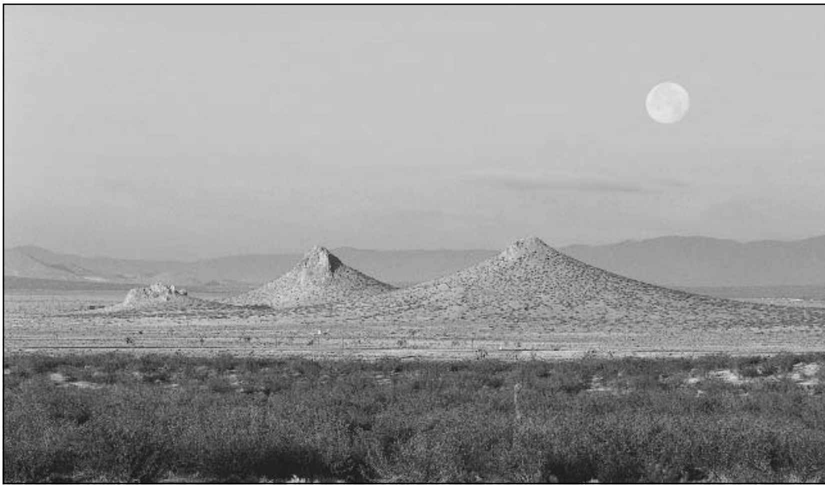


Moonrise over California's Mojave Desert. (PhotoDisc)

Desert Landforms

Deserts are often striking in color, form, or both. The underlying lack of water in deserts produces unique desert features not found in humid regions. Arid lands cover approximately 30 percent of the earth's land surface, an area of about 15.4 million square miles (40 million sq. km.). Arid lands include deserts and surrounding steppes, semiarid regions that act as transition zones between arid and humid lands.

Many of the world's largest and driest deserts are found between 20 and 40 degrees north and south latitude. These include the Mojave and Sonoran Deserts of the United States, the Sahara in northern Africa, and the Great Sandy Desert in Australia. In these deserts, the subtropical high prevents cloud formation and precipitation while increasing rates of surface evaporation.

Some arid lands, like China's Gobi Desert, form because they are far from oceans, which are the dominant source for atmospheric water vapor and precipitation. Others, like California's Death Valley, are arid because mountain ranges block mois-

Death Valley Playa

California's Death Valley is the driest desert in the United States, with an average rainfall of only 1.5 inches (38 millimeters) per year at the town of Furnace Creek. It is also consistently one of the hottest places on Earth, with a record high of 134 degrees Fahrenheit (57 degrees Celsius). In the distant past, however, Death Valley held lakes that formed in response to global cooling. Over 120,000 years ago, Death Valley hosted a 295-foot-deep (90-meter) body of water called Lake Manley. Evidence of this lake remains in evaporite deposits that make up the playa in the valley's center, in wave-cut shorelines, and in beach bars.

ture coming from the sea. The combination of mountain barriers and very low elevations makes Death Valley the hottest, driest desert in North America.

Sand Dunes. Many people envision deserts as vast expanses of blowing sand. Although wind plays a more important role in deserts than it does elsewhere, only about 25 percent of arid lands are covered by sand. Broad regions that are covered entirely in sand (such as portions of northwestern Africa, Arabia, and Australia) are referred to as sand seas. Why is wind more effective here than elsewhere?

The lack of soil water and vegetation, both of which act to bind grains together, allows enhanced eolian (wind) erosion. Very small particles are picked up and suspended within the moving air mass, while sand grains bounce along the surface. Removal of material often leaves behind depressions called blowouts or deflation hollows. Moving grains abrade cobbles and boulders at the surface, creating uniquely sculpted and smoothed rocks known as ventifacts. Bedrock outcrops can be streamlined as they are blasted by wind-borne grains to form features called yardangs. As these rocks are ground away, they contribute additional sediment to the wind.

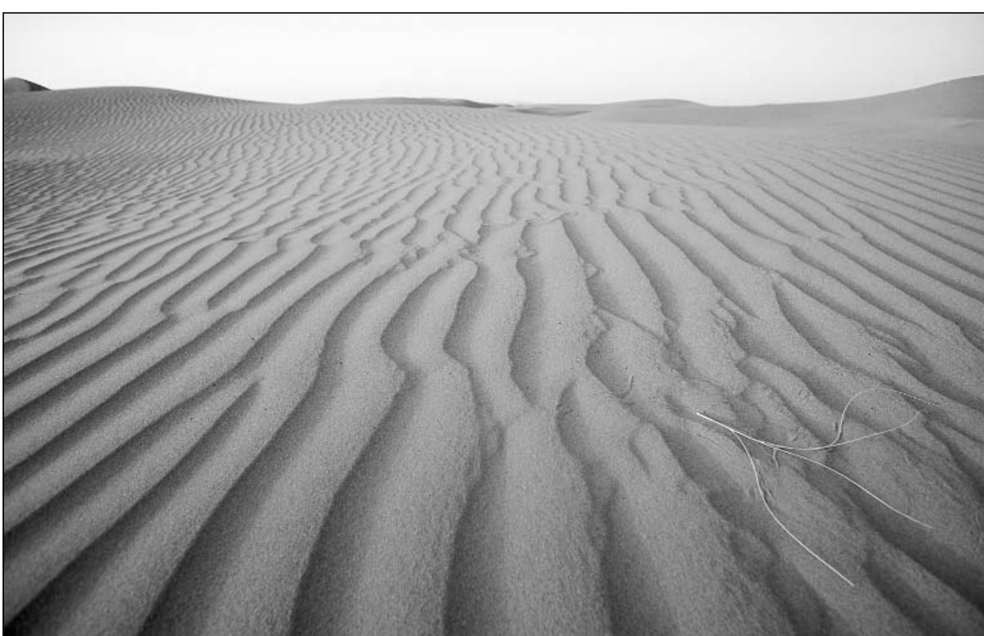
Desert sand dunes are not stationary features—instead, they represent accumulations of moving sand. Wind blows sand along the desert floor. Where it collects, it forms dunes. Typically, dunes have relatively shallow windward faces and steeper slip faces. Sand grains bounce up the wind-

Sand dunes such as these conform to popular images of desert landforms; however, only about 25 percent of arid lands are covered by sand. (PhotoDisc) ward face then eventually cascade down the slip face, the movement of individual grains driving movement of the entire dune in a downwind direction.

Four major dune types are found within arid regions. Barchan dunes are crescent-shaped features, with arms that point downwind. They may occur as isolated structures or within fields. They form where winds blow in a single direction and where the supply of sand is limited. With a larger supply of sand, barchan dunes can join with one another to form a transverse dune field.

There, ridges are perpendicular to the predominant wind direction. With quartering winds (that is, winds that vary in direction throughout a range of about 45 degrees) dune ridges form that are parallel to the average wind direction. These so-called longitudinal dunes have no clearly defined windward and slip faces. Where winds blow sand from all directions, star dunes form. Sand collects in the middle of the feature to form a peaked center with arms that spiral outward.

Badlands, Mesas, and Buttes. As scarce as it may be, water is still the dominant force in shaping desert landscapes. Annual precipitation may be low, but the amount of precipitation in a single storm may be a large fraction of the yearly total. An arid landscape that is underlain by poorly cemented rock or sediment, such as that found in western South Dakota, may form badlands as a result of the erosive ability of storm-water runoff. Overall aridity prevents vegetation from establishing the interconnected root system that holds soil particles together in more humid regions.



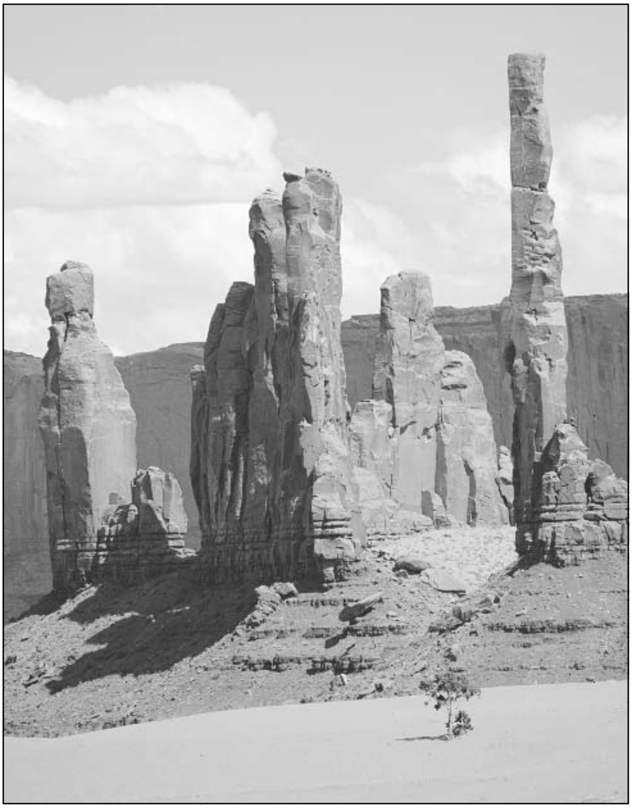
Transverse dune field in the Moroccan Sahara. (Corbis)

Badlands National Park in South Dakota is a good example of desert badlands that are largely devoid of vegetation and erode rapidly during storms. (PhotoDisc)

Cloudbursts cause rapid erosion that forms numerous gullies, deeply incised washes, and hoodoos. The latter structures are created when rock or sediment that is more resistant protects underlying material from erosion. Over time, protected sections stand as prominent spires while surrounding material is removed. Landscapes like those found in Badlands National Park in South Dakota are devoid of vegetation and erode rapidly during storms.

Arid regions that are underlain by flat-lying rock units can form mesas and buttes. Water follows fractures and other lines of weakness, forming ever-widening canyons. Over time, these grow into broad valleys. In northern Arizona's Monument Valley, remnants of original bedrock stand as isolated, flat-topped structures. Broad mesas are marked by their flat tops (made of a resistant rock like sandstone or basalt) and steep sides. Buttes are much narrower, with a small resistant cap, but are often as tall and steep as neighboring mesas.

Desert Pavement and Desert Varnish. Much of the desert floor is covered by desert pavement, an accumulation of gravel and cobbles that forms a surface fabric that can interconnect tightly. Fine material has been removed by wind and water, leaving behind larger fragments that inhibit further erosion. In many areas, desert pavements have been stable for long periods of time, as evidenced by their surface patina of desert



The isolated, flat-topped pillars in Arizona's Monument Valley are actually remnants of original bedrock, standing in broad valleys formed over time by water that followed fractures and other lines of weakness and formed ever-widening canyons. (PhotoDisc)

varnish. Desert varnish is a thin outer coating of wind-deposited clay mixed with iron and manganese oxides. Varying in color from light brown to black, these coatings are thought to adhere to rocks by the action of single-celled microorganisms. Under a microscope, desert varnish can be seen to be made up of very fine layers. A thick, dark patina means that a rock has been exposed for a long time.

Playas. Where neither dunes nor rocky pavements cover the desert floor, one may find an accumulation of saline minerals. A playa is a flat surface that is often blindingly white in color. Playas are usually found in the centers of desert valleys and contain material that mineralized during the evaporation of a lake. Dry lake beds are a common feature of the Great Basin in the western United States. During glacial stages, the last of which occurred about twenty thousand years ago, lakes grew in what are now arid, closed valleys. As the climate warmed, these lakes shrank, and many dried completely. As a lake evaporates, minerals that were held in solution crystallize, forming salts, including halite (table salt). These salt deposits frequently are mined for useful household and industrial chemicals.

Richard L. Orndorff

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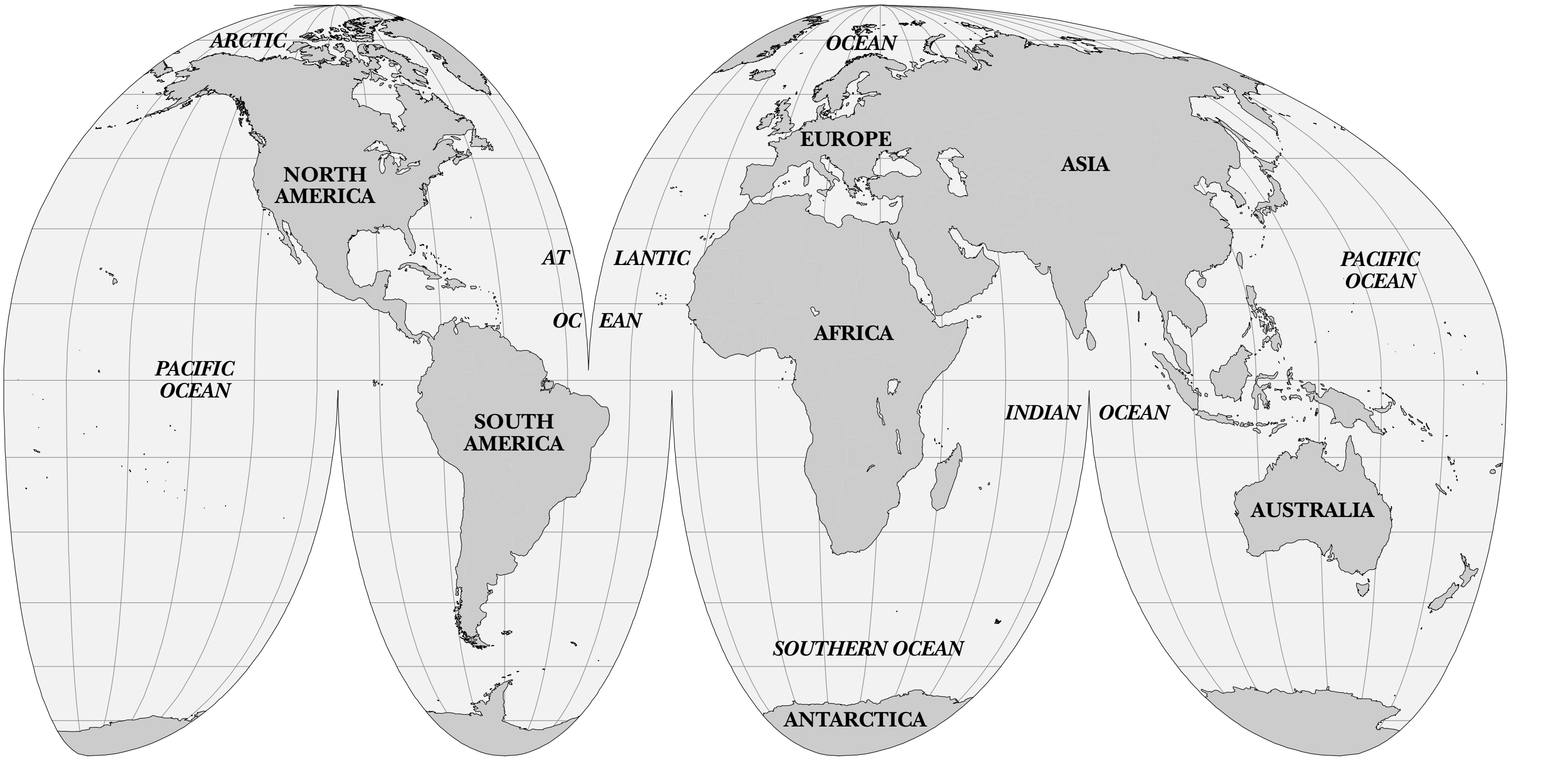
Ocean Margins

Ocean margins are the areas where land borders the sea. Although often referred to as coastlines or beaches, ocean margins cover far greater territory than beaches. An ocean margin extends from the coastal plain—the fertile farming belt of land along the seacoast—to the edge of the gently sloping land submerged in water, called the continental shelf.

Ocean margin constitutes 8 percent of the world's surface. It is rich in minerals, both above and below water, and is home to 25 percent of Earth's people, along with 90 percent of the marine life. This fringe of land at the border of the ocean is ever changing. Tides wash sediment in and leave it behind, just below sea level. This process, called deposition, builds up land in some areas of the coastline. At the same time, ocean waves, winds, and storms wear away or erode parts of the shoreline. As land is worn away or built up, the amount of land above sea level changes. Factors such as climate, erosion, deposition, changes in sea level, and the effects of human activity constantly change the shape of the ocean margin on Earth.

Beach Dynamics. The two types of coasts or land formations at the ocean margin are primary coasts and secondary coasts. Primary coasts are formed by systems on land, such as the melting of glaciers, wind or water erosion, and sediment deposited by rivers. Deltas and fjords are examples of primary coasts. Secondary coasts are formed by ocean patterns, such as erosion by waves or currents, sediment deposition by waves or currents, or changes by marine plants or animals. Beaches, coral reefs, salt marshes, and mangrove swamps are examples of secondary coasts.

Oceans and Continents



Sediment carried by rivers to the sea is deposited to form deltas at the mouths of the rivers. Some of the sediment can wash out to sea, causing formations to build up at a distance from the shore. These formations eventually become barrier islands, which are often little more than 10 feet (3 km.) above sea level. As a consequence, heavy storms, such as hurricanes, can cause great damage to barrier islands. Barrier islands naturally protect the coastline from erosion, however, especially during heavy coastal storms.

Sea level changes also affect the shape of the coastline. As oceans slowly rise, land is slowly consumed by the ocean. Barrier islands, having low sea levels, may slowly be covered with water. The melting of continental glaciers increased the sea level 0.06 inch (0.15 centimeter) per year during the twentieth century. As ocean waters warm, they expand, eating away at sea levels. Global warming caused by carbon dioxide levels in the atmosphere could cause sea levels to rise as much as 0.24 inch (0.6 centimeter) per year as a result of the warming of the water and glacial melting.

Human Influence. The shape of the ocean margin also changes radically as a result of human influence. According to the United States Geo-

Ships discharging wastes or spilling oil can cause catastrophic damage to ecosystems along ocean margins. (PhotoDisc) logical Survey, half of the people living in the United States live within fifty miles (80.5 km.) of the coasts. Pollution from toxins, dredging, recreational boating, and waste disposal kills plants and animals along the ocean margin. This changes the coastal shape, as mangrove forests, coral reefs, and other coastal lifeforms die.

A greater concern along the coastal fringe, however, is human development. Not only are people drawn to the fertile soil along the coastal zone of the continent, but they also develop islands and coves into resort communities. To protect homes and hotels along the coastal zone from coastal erosion, people build breakwalls, jetties, and sand and stone bars called groins.

These human-made barriers disrupt the natural method by which the ocean carries material along the coast. Longshore drift, a zigzag movement, deposits sediment from one area of the beach farther along the shoreline. Breakwalls, jetties, and groins disrupt this flow. As the ocean smashes against a breakwall, the property behind it may be safe for the present, but the coastline neighboring the breakwall takes a greater beating. The silt and sediment from upshore, which would replace that carried downshore, never arrives. Eventually, the breakwall will break down

Pollution from toxins, dredging, recreational boating, and careless waste disposal kills plants and animals along the ocean margin, making the water unhealthful even to humans. (PhotoDisc)

A groin built to protect the coastline of Cape Hatteras, North Carolina, traps sand that normally moves along the shoreline. (U.S. Geological Survey)

under the impact of the ocean force. Areas with breakwalls and jetties often suffer greater damage in coastal storms than areas that remain naturally open to the changing forces of the ocean.

To compensate for the destructive nature of artificial barriers, many recreational beaches replace lost sand with dredgings or deposit truckloads of sand from inland sources. For example, Virginia Beach in the United States spends $800,000 annually to restore beaches for the tourist season in this way.

Despite the changes in the shape of the ocean margin, it continues to provide a stable supply of resources—fish, seafood, minerals, sponges, and other marine plants and animals. Offshore drilling of oil and natural gas often takes place within 200 miles (322 km.) of shorelines.

Lisa A. Wroble

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Information on the World Wide Web

Ocean Planet, part of a traveling exhibit prepared by the Smithsonian Institution, features interesting facts on oceans and ocean margins. (seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML/oceanography_geography.html)

The National Oceanic and Atmospheric Administration (NOAA) home page provides maps, photos, and links to general information about NOAA programs involving the ocean, coastlines, and weather relationships. (www.noaa.gov/)

The Globe Program is a worldwide program in which schools help scientists with data collection as students learn about science in their own regions of the world. Student findings are posted to the Globe Web site and are accessible to computer users. (www.globe.gov/)

Earth's Climates

The Atmosphere

The thin layer of gases that envelops the earth is the atmosphere. This layer is so thin that if the earth were the size of a desktop globe, more than 99 percent of its atmosphere would be contained within the thickness of an ordinary sheet of paper. Despite its thinness, the atmosphere sustains life on Earth, protecting it from the Sun's searing radiation and regulating the earth's temperature. Storms of the atmosphere carry water to the continents, and weathering by its wind and rain helps shape their form.

Composition of the Atmosphere. The earth's atmosphere consists of gases, microscopic particles called aerosol, and clouds consisting of water droplets and ice particles. Its two principal gases are nitrogen and oxygen. In dry air, nitrogen occupies 78 percent, and oxygen 21 percent, of the atmosphere's volume. Argon, neon, xenon, helium, hydrogen, and other trace gases together equal less than 1 percent of the remaining volume.

These gases are distributed homogeneously in a layer called the homosphere, which occurs between the earth's surface and about 50 miles (80 km.) altitude. Above 50 miles altitude, in the heterosphere, the concentration of heavier gases decreases more rapidly than lighter gases.

The atmosphere has no firm top. It simply thins out until the concentration of its gas molecules approaches that of the gases in outer space. The concentration of nitrogen and oxygen remains essentially constant in the atmosphere because a balance exists between the production and removal of these gases at the earth's surface. Decaying organic matter adds nitrogen to the atmosphere, while soil bacteria remove nitrogen. Oxygen enters the atmosphere primarily through photosynthesis and is removed through animal respiration, combustion, and decay of organic material, and by chemical reactions involving the creation of oxides.

The atmosphere contains many gases that are present in small, variable concentrations. Three gases—water vapor, carbon dioxide and ozone—are vital to life on Earth. Water vapor enters the atmosphere through evaporation, primarily from the oceans, and through transpiration by plants. It condenses to form clouds, which provide the rain and snow that sustain life outside the oceans. The concentration of water vapor varies from about 4 percent by volume in tropical humid climates to a small fraction of a percent in polar dry climates. Water vapor plays an important role in regulating the temperature of the earth's surface and the atmosphere. Clouds reflect some of the incoming solar radiation, while water vapor and clouds both absorb earth's infrared radiation.

Carbon dioxide also absorbs the earth's infrared radiation. The concentration of carbon dioxide, about 0.037 percent by volume at the turn of the millennium, has increased about 25 percent since the early nineteenth century. Carbon dioxide enters the atmosphere as the result of decay of organic material, through respiration, during volcanic eruptions, and from the burning of fossil fuels. It is removed during photosynthesis and by dissolving in ocean water, where it is used by organisms and converted to carbonates. The increase in atmospheric carbon dioxide associated with the burning of fossil fuels has raised concerns that the earth's atmosphere may be warming through enhancement of the greenhouse effect.

Ozone, a gas consisting of molecules containing three oxygen atoms, forms in the upper atmosphere when oxygen atoms and oxygen molecules combine. Most ozone exists in the upper atmosphere between 15 and 20 miles (25-35 km.) in altitude, in concentrations of no more than 0.002 percent by volume. This small amount of ozone sustains life outside the oceans by absorbing most of the Sun's ultraviolet radiation, thereby shielding the earth's surface from the radiation's harmful effects on living organisms. Paradoxically, ozone is an irritant near the earth's surface

The Ozone Hole

Since the 1970's, balloon-borne and satellite measurements of stratospheric ozone have shown rapidly declining stratospheric ozone concentrations over the continent of Antarctica, termed the "ozone hole." The lowest concentrations occur during the Antarctic spring, in September and October. The decrease in ozone has been associated with an increase in the concentration of chlorine, a gas introduced into the stratosphere through chemical reactions involving sunlight and chlorofluorocarbons, synthetic chemicals used primarily as refrigerants. The ozone hole over Antarctica has raised concern about possible worldwide reduction in the concentration of upper atmospheric ozone.

and is the major component of photochemical smog. Other gases that contribute to pollution include methane, nitrous oxide, hydrocarbons, and chlorofluorocarbons.

Aerosols represent another component of atmospheric pollution. Aerosols form in the atmosphere during chemical reactions between gases, through mechanical or chemical interactions between the earth, ocean surface and atmosphere, and during evaporation of droplets containing dissolved or solid material. These microscopic particles are always present in air, with concentrations of about a few hundred per cubic centimeter in clean air to as many as a million per cubic centimeter in polluted air. Aerosols are essential to the formation of rain and snow, because they serve as centers upon which cloud droplets and ice particles form.

Energy Exchange in the Atmosphere. The Sun is the ultimate source of the energy in Earth's atmosphere. Its radiation, called electromagnetic radiation because it propagates as waves with electric and magnetic properties, travels to the surface of the earth's atmosphere at the speed of light. This energy spans many wavelengths, some of which the human eye perceives as colors. Visible wavelengths make up about 44 percent of the Sun's energy. The remainder of the Sun's radiant energy cannot be seen by human eyes. About 7 percent arrives as ultraviolet radiation, and most of the remaining energy is infrared radiation.

The Sun is not the only source of radiation. All objects emit and absorb radiation to some degree. Cooler objects such as the earth emit nearly all their energy at infrared wavelengths. Objects heat when they absorb radiation and cool when they emit radiation. The radiation emitted by the earth and atmosphere is called terrestrial radiation.

The balance between absorption of solar radiation and emission of terrestrial radiation ultimately determines the average temperature of the earth-atmosphere system. The vertical temperature distribution within the atmosphere also depends on the absorption and emission of radiation within the atmosphere, and the transfer of energy by the processes of conduction, convection, and latent heat exchange. Conduction is the direct transfer of heat from molecule to molecule. This process is most important in transferring heat from the earth's surface to the first few centimeters of the atmosphere. Convection, the transfer of heat by rising or sinking air, transports heat energy vertically through the atmosphere.

Latent heat is the energy required to change the state of a substance, for example, from a liquid to a gas. Energy is transferred from the earth's surface to the atmosphere through latent heat exchange when water evaporates from the oceans and condenses to form rain in the atmosphere.

Only 51 percent of the solar energy reaching the top of the earth's atmosphere is absorbed by the earth's surface. The atmosphere absorbs another 19 percent. The remaining 30 percent is scattered back to space by atmospheric gases, clouds and the earth's surface. To understand the importance of terrestrial radiation and the greenhouse effect in the atmosphere's energy balance, consider the solar radiation arriving at the top of the earth to be 100 energy units, with 51 energy units absorbed by the earth's surface and 19 units by the atmosphere.

The earth's surface actually emits 117 units of energy upward as terrestrial radiation, more than twice as much energy as it receives from the Sun. Only 6 of these units are radiated to space—the atmosphere absorbs the remaining energy. Latent heat exchange, conduction, and convection account for another 30 units of energy transferred from the surface to the atmosphere. The atmosphere, in turn, radiates 96 units of energy back to the earth's surface (the greenhouse effect), and 64 units to space. The earth's and atmosphere's energy budget remains in balance, the atmosphere gaining and losing 160 units of energy, and the earth gaining and losing 147 units of energy.

The Greenhouse Effect

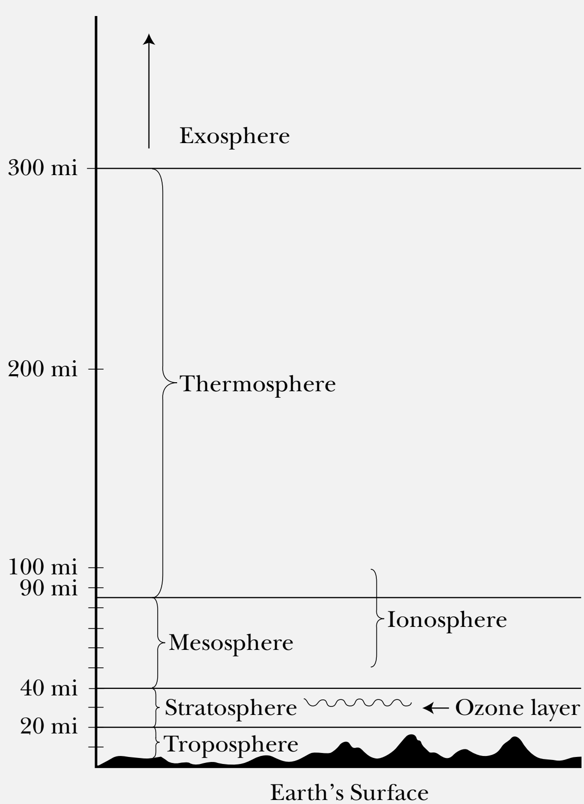
Clouds and atmospheric gases such as water vapor, carbon dioxide, methane, and nitrous oxide absorb part of the infrared radiation emitted by the earth's surface and reradiate part of it back to the earth. This process effectively reduces the amount of energy escaping to space and is popularly called the "greenhouse effect" because of its role in warming the lower atmosphere. The greenhouse effect has drawn worldwide attention because increasing concentrations of carbon dioxide from the burning of fossil fuels may result in a global warming of the atmosphere.

Scientists know that the greenhouse analogy is incorrect. A greenhouse traps warm air within a glass building where it cannot mix with cooler air outside. In a real greenhouse, the trapping of air is more important in maintaining the temperature than is the trapping of infrared energy. In the atmosphere, air is free to mix and move about.

Vertical Structure of the Atmosphere. Temperature decreases rapidly upward away from the earth's surface, to about –58 degrees Fahrenheit (–50 degrees Celsius) at an altitude of about 7.5 miles (12 km.). Above this altitude, temperature increases with height to about 32 degrees Fahrenheit (0 degrees Celsius) at an altitude of 31 miles (50 km.). The layer of air in the lower atmosphere where temperature decreases with height is called the troposphere. It contains about 75 percent of the atmosphere's mass. The layer of air above the troposphere, where temperature increases with height, is called the stratosphere. All but 0.1 percent of the remaining mass of the atmosphere resides in the stratosphere.

The stratosphere exists because ozone in the stratosphere absorbs ultraviolet light and converts it to heat. The boundary between the troposphere and stratosphere is called the tropopause. The tropopause is extremely important because it acts as a lid on the earth's weather. Storms

Layers of the Earth's Atmosphere



can grow vertically in the troposphere, but cannot rise far, if at all, beyond the tropopause. In the polar regions, the tropopause can be as low as 5 miles (8 km.) above the surface, while in the Tropics, the tropopause can be as high as 11 miles (18 km.). For this reason, tropical storms can extend to much higher altitudes than storms in cold regions.

The mesosphere extends from the top of the stratosphere, the stratopause, to an altitude of about 56 miles (90 km.). Temperature decreases with height within the mesosphere. The lowest average temperatures in the atmosphere occur at the mesopause, the top of the mesosphere, where the temperature is about –130 degrees Fahrenheit (–90 degrees Celsius). Only 0.0005 percent of the atmosphere's mass remains above the mesopause. In this uppermost layer, the thermosphere, there are few atoms and molecules. Oxygen molecules in the thermosphere absorb high-energy solar radiation. In this near vacuum, absorption of even small amounts of energy causes a large increase in temperature. As a result, temperature increases rapidly with height in the lower thermosphere, reaching about 1,300 degrees Fahrenheit (700 degrees Celsius) above 155 miles (250 km.) altitude.

The upper mesosphere and thermosphere also contain ions, electrically charged atoms or molecules. Ions are created in the atmosphere when air molecules collide with high-energy particles arriving from space or absorb high-energy solar radiation. Ions cannot exist very long in the lower atmosphere, because collisions between newly formed ions quickly restore ions to their uncharged state. However, above about 37 miles (60 km.) collisions are less frequent and ions can exist for longer times. This region of the atmosphere, called the ionosphere, is particularly important for amplitude-modulated (AM) radio communication because it reflects standard AM radio waves. At night, the lower ionosphere disappears as ions recombine, allowing AM radio waves to travel longer distances when reflected. For this reason, AM radio station signals can sometimes travel great distances at night.

The top of the atmosphere occurs at about 310 miles (500 km.). At this altitude, the distance between individual molecules is so great that energetic molecules can move into free space without colliding with neighbor molecules. In this uppermost layer, called the exosphere, the earth's atmosphere merges into space.

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Global Climates

A region's climate is the sum of its long-term weather conditions. Most descriptions of climate emphasize temperature and precipitation characteristics, because these two climatic elements usually exert more impact on environmental conditions and human activities than do other elements, such as wind, humidity, and cloud cover. Climatic descriptions of a region generally cover both mean conditions and extremes. Climatic means are important because they represent average conditions that are frequently experienced; extreme conditions, such as severe storms, excessive heat and cold, and droughts, are important because of their adverse impact.

Important Climate Controls. A region's climate is largely determined by the interaction of six important natural controls: sun angle, elevation, ocean currents, land and water heating and cooling characteristics, air pressure and wind belts, and orographic influence.

Sun angle—the height of the Sun in degrees above the nearest horizon—largely controls the amount of solar heating that a site on Earth receives. It strongly influences the mean temperatures of most of the earth's surface, because the Sun is the ultimate energy source for nearly all the atmosphere's heat. The higher the angle of the Sun in the sky, the greater the concentration of energy, per unit area, on the earth's surface (assuming clear skies). From a global perspective, the Sun's mean angle is highest, on average, at the equator, and becomes progressively lower poleward. This causes a gradual decrease in mean temperatures with increasing latitude.

Sun angles also vary seasonally and daily. Each hemisphere is inclined toward the Sun during spring and summer, and away from the Sun during fall and winter. This changing inclination causes mean sun angles to be higher, and the length of daylight longer, during the spring and summer. Therefore, most locations, especially those outside the Tropics, have warmer temperatures during these two seasons. The earth's rotation causes sun angles to be higher during midday than in the early morning and late afternoon, resulting in warmer temperatures at midday. Heating and cooling lags cause both seasonal and daily maximum and minimum temperatures typically to occur somewhat after the periods of maximum and minimum solar energy receipt.

Variations in elevation—the distance above sea level—can cause locations at similar latitudes to vary greatly in temperature. Temperatures decrease an average of about 3.5 degrees Fahrenheit per thousand feet (6.4 degrees Celsius per thousand meters). Therefore, high mountain and plateau stations are much colder than low-elevation stations at the same latitude.

Surface ocean currents can transport masses of warm or cold water great distances from their source regions, affecting both temperature and moisture conditions. Warm currents facilitate the evaporation of copious amounts of water into the atmosphere and add buoyancy to the air by heating it from below. This results in a general increase in precipitation totals. Cold currents evaporate water relatively slowly and chill the overlying air, thus stabilizing it and reducing its potential for precipitation.

The influence of ocean currents on land areas is greatest in coastal regions and decreases inland. The west coasts of continents (except for Europe) generally are paralleled by relatively cold currents, and the east coasts by relatively warm currents. For example, the warm Gulf Stream flows northward off the eastern United States, while the West Coast is cooled by the southward-flowing California Current.

Land can change temperature much more readily than water. As a result, the air over continents typically experiences larger annual temperature ranges (that is, larger temperature differences between summer and winter) and shorter heating and cooling lags than does the air over oceans. This same effect causes continental interiors and the leeward (downwind) coasts of continents typically to have larger temperature ranges than do windward (upwind) coasts. Climates that are dominated by air from landmasses are often described as continental climates. Conversely, climates dominated by air from oceans are described as maritime climates.

The seasonal heating and cooling of continents can also produce a monsoon influence, which has to do with annual shifts of wind patterns. Areas influenced by a monsoon, such as Southeast Asia, tend to have a predominantly onshore flow of moist maritime air during the summer. This often produces heavy rains. An offshore flow of dry air predominates in winter, producing fair weather.

Earth's atmosphere displays a banded, or beltlike, pattern of air pressure and wind systems. High pressure is associated with descending air and dry weather; low pressure is associated with rising air, which produces cloudiness and often precipitation. Wind is produced by differences in air pressure. The air blows outward from high-pressure systems and into low-pressure systems in a constant attempt to equalize air pressures.

The direction and speed of movement of weather systems, such as weather fronts and storms, are controlled by wind patterns, especially those several kilometers above the surface. The seasonal shift of global temperatures caused by the movement of the Sun's vertical rays between the Tropics of Cancer and Capricorn produces a latitudinal migration of both air pressure and wind belts. This shift affects the annual temperature and precipitation patterns of many regions.

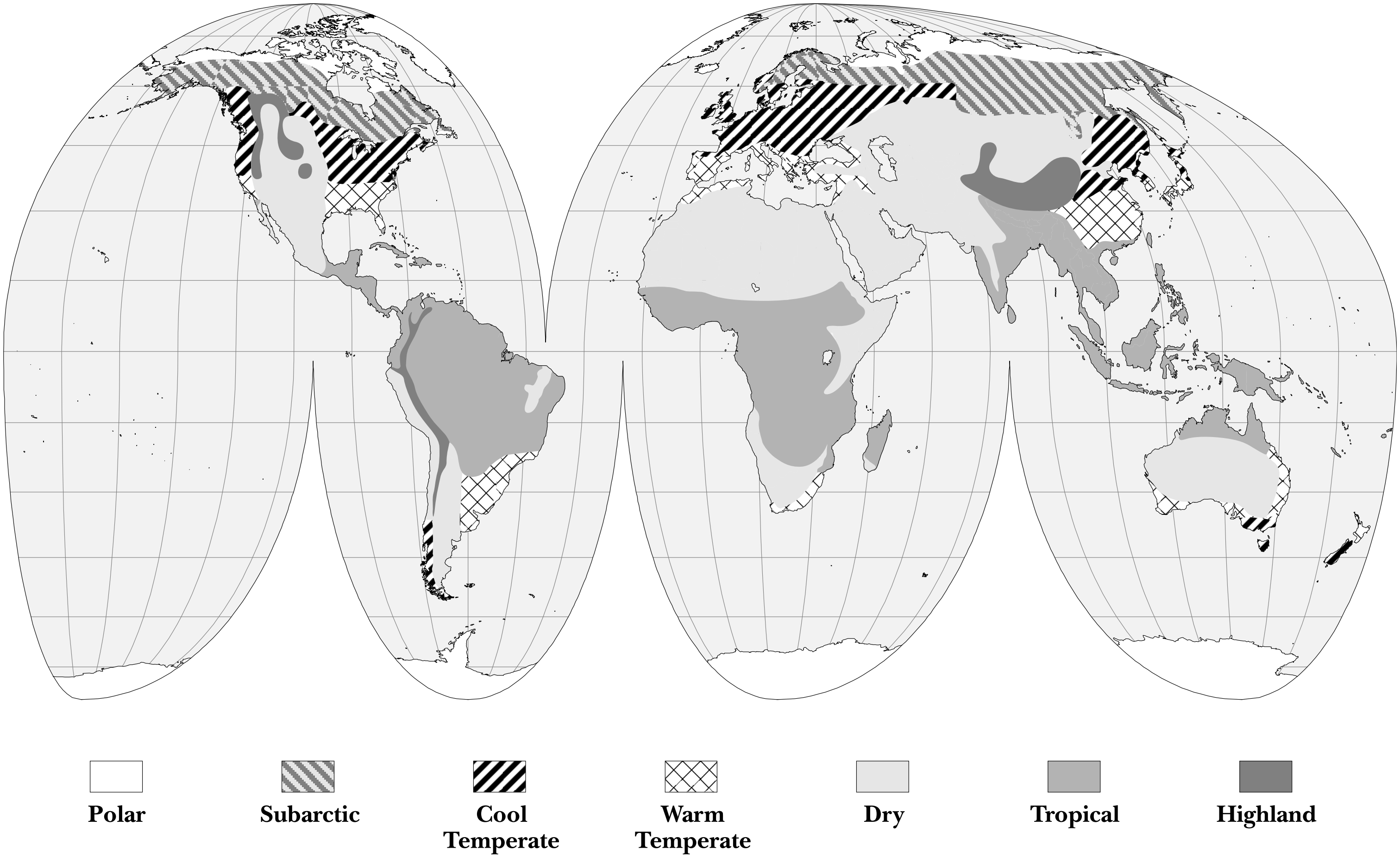
Four air-pressure belts exist in each hemisphere. The intertropical convergence zone (ITCZ) is a broad belt of low pressure centered within a few degrees of latitude of the equator. The subtropical highs are high-pressure belts centered near 30 degrees north and south latitude, which are responsible for many of the world's deserts. The subpolar lows are low-pressure belts centered about 60 or 65 degrees north and south latitude. Finally, the polar highs are high-pressure centers located near the North and South Poles.

The air pressure gradient between these belts produces the earth's major wind belts. The regions between the ITCZ and the subtropical highs are dominated by the trade winds, a broad belt in each hemisphere of easterly (that is, moving east to west) winds. The middle latitudes are mostly situated between the subtropical highs and the subpolar lows and are within the westerly wind belt. This wind belt causes winds, and weather systems, to travel generally from west to east in the United States and Canada. Finally, the high-latitude zones between the subpolar lows and polar highs are situated within the polar easterlies.

The final factor affecting climate—orographic influence—is the lifting effect of mountain peaks or ranges on winds that pass over them. As air approaches a mountain barrier, it rises, typically producing clouds and precipitation on the windward (upwind) side of the mountains. After it crosses the crest, it descends the leeward (downwind) side of the mountains, generally producing dry weather. Most of the world's wettest locations are found on the windward sides of high mountain ranges; some deserts, such as those of the western interior United States, owe their aridity to their location on the leeward sides of orographic barriers.

World Climate Types. The global distribution of the world climate controls is responsible for the development of fourteen widely recognized climate types. In this section, the major characteristics of each of these climates will be briefly described. The climates are discussed in a rough poleward sequence.

World Climate Regions



Tropical Wet Climate. Sometimes called the tropical rain forest climate, the tropical wet climate exists chiefly in areas lying within 10 degrees of the equator. It is an almost seasonless climate, characterized by year-round warm, humid, rainy conditions that allow land areas to support a dense broadleaf forest cover. The warm temperatures, which for most locations average near 80 degrees Fahrenheit (27 degrees Celsius) throughout the year, result from the constantly high midday sun angles experienced at this low latitude. The heavy precipitation totals result from the heating and subsequent rising of the warm moist air to form frequent showers and thunderstorms, especially during the afternoon hours. The dominance of the ITCZ enhances precipitation totals, helping make this climate type one of the world's rainiest.

Tropical Monsoonal Climate. The tropical monsoonal climate occurs in low-latitude areas, such as Southeast Asia, that have a warm, rainy climate with a short dry season. Temperatures are similar to those of the tropical wet climate, with the warmest weather often occurring during the drier period, when sunshine is more abundant. The heavy rainfalls result from the nearness of the ITCZ for much of the year, as well as the dominance of warm, moist air masses derived from tropical oceans. During the brief dry season, however, the ITCZ has usually shifted into the opposite hemisphere, and windflow patterns often have changed so as to bring in somewhat drier air derived from continental sources.

Tropical Savanna Climate. The tropical savanna climate, also referred to as the tropical wet and dry climate, occupies a large portion of the Tropics between 5 and 20 degrees latitude in both hemispheres. It experiences a distinctive alternation of wet and dry seasons, caused chiefly by the seasonal shift in latitude of the subtropical highs and ITCZ. Summer is typically the rainy season because of the domination of the ITCZ. In many areas, an onshore windflow associated with the summer monsoon increases rainfalls at this time. In winter, however, the ITCZ shifts into the opposite hemisphere and is replaced by drier and more stable air associated with the subtropical high. In addition, the winter monsoon tendency often produces an outflow of continental air. The long dry season inhibits forest growth, so vegetation usually consists of a cover of drought-resistant shrubs or the tall savanna grasses after which the climate is named.

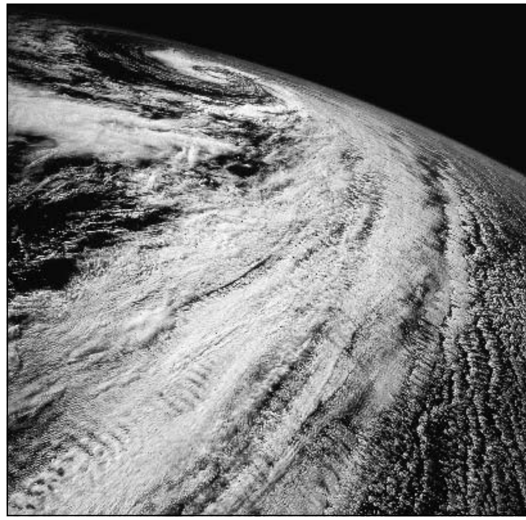
Subtropical Desert Climate. The subtropical desert climate has hot, arid conditions as a result of the year-round dominance of the subtropical highs. Summertime temperatures in this climate soar to the highest readings found anywhere on earth. The world's record high temperature was 136.4 degrees Fahrenheit (58 degrees Celsius), recorded in El Azizia, Libya, in the northern Sahara Desert. Rainfall totals in this type of climate are generally less than 10 inches (25 centimeters) per year. What rainfall does occur often arrives as brief, sometimes violent, afternoon thunderstorms. Although summer temperatures are extremely hot, the dry air enables rapid cooling during the winter, so that temperatures are cool to mild at this time of year.

Subtropical Steppe Climate. The subtropical steppe climate is a semi-arid climate, found mostly on the margins of the subtropical deserts. Precipitation usually ranges from 10 to 30 inches (25 to 75 centimeters), sufficient for a ground cover of shrubs or short steppe grasses. Areas on the equatorward margins of subtropical deserts typically receive their precipitation during a brief showery period in midsummer, associated with the poleward shift of the ITCZ. Areas on the poleward margins of the subtropical highs receive most of their rainfall during the winter, due to the penetration of cyclonic storms associated with the equatorward shift of the westerly wind belt.

Mediterranean Climate. The Mediterranean climate, also sometimes referred to as the dry summer subtropics, has a distinctive pattern of dry summers and more humid, moderately wet winters. This pattern is caused by the seasonal shift in latitude of the subtropical high and the westerlies. During the summer, the subtropical high shifts poleward into the Mediterranean climate regions, blanketing them with dry, warm, stable air. As winter approaches, this pressure center retreats equatorward, allowing the westerlies, with their eastward-traveling weather fronts and cyclonic storms, to overspread this region. The Mediterranean climate is found on the windward sides of continents, particularly the area surrounding the Mediterranean Sea and much of California. This results in the predominance of maritime air and relatively mild temperatures throughout the year.

Humid Subtropical Climate. The humid subtropical climate is found on the eastern, or leeward, sides of continents in the lower middle latitudes. The most extensive land area with this climate is the southeastern United States, but it is also seen in large areas in South America, Asia, and Australia. Temperature ranges are moderately large, with warm to hot summers and cool to mild winters. Mean temperatures for a given location are dictated largely by latitude, elevation, and proximity to the coast. Precipitation is moderate. Winter precipitation is usually associated with weather fronts and cyclonic storms that travel eastward within the westerly wind belt. During summer, most precipitation is in the form of brief, heavy afternoon and evening thunderstorms. Some coastal areas are subject to destructive hurricanes during the late summer and autumn.

Midlatitude Desert Climate. This type of climate consists of areas within the western United States, southern South America, and Central Asia that have arid conditions resulting from the moisture-blocking influence of mountain barriers. This climate is highly continental, with warm summers and cold winters. When precipitations occurs, it frequently comes in the form of winter snowfalls associated with weather fronts and cyclonic storms. Rainfall in summer typically occurs as afternoon thunderstorms.



Satellite image of storm patterns over the surface of the earth. (PhotoDisc)

Midlatitude Steppe. The midlatitude steppe climate is located in interior portions of continents in the middle latitudes, particularly in Asia and North America. This climate has semiarid conditions caused by a combination of continentality resulting from the large distance from oceanic moisture sources and the presence of mountain barriers. Like the midlatitude desert climate, this climate has large annual temperature ranges, with cold winters and warm summers. It also receives winter rains and snows chiefly from weather fronts and cyclonic storms; summer rains occur largely from afternoon convectional storms. In the Great Plains of the United States, spring can bring very turbulent conditions, with blizzards in early spring and hailstorms and tornadoes in mid to late spring.

Marine West Coast. This type of climate is typically located on the west coasts of continents just poleward of the Mediterranean climate. Its location in the heart of the westerly wind belt on the windward sides of continents produces highly maritime conditions. As a result, cloudy and humid weather is common, along with frequent periods of rainfall from passing weather fronts and cyclonic storms. These storms are often well developed in winter, resulting in extended periods of wet and windy weather. Precipitation amounts are largely controlled by the presence and strength of the orographic effect; mountainous coasts like the northwestern United States and the west coast of Canada are much wetter than are flatter areas like northern Europe. Temperatures are held at moderate levels by the onshore flow of maritime air. As a consequence, winters are relatively mild and summers relatively cool for the latitude.

Humid Continental Climate. The humid continental climate is found in the northern interiors of Eurasia (Europe and Asia) and North America. It does not occur in the Southern Hemisphere because of the absence of large land masses in the upper midlatitudes of that hemisphere. This climate type is characterized by low to moderate precipitation that is largely frontal and cyclonic in nature. Most precipitation occurs in summer, but cold winter temperatures typically cause the surface to be frozen and snow-covered for much of the late fall, winter, and early spring. Temperature ranges in this climate are the largest in the world. In Siberia, for example, mean temperatures in July can average more than 108 degrees Fahrenheit (60 degrees Celsius) warmer than in January. Winter temperatures in parts of both North America and Siberia can fall well below –58 degrees Fahrenheit (–50 degrees Celsius), making these the coldest permanently settled sites in the world.

Tundra Climate. The tundra climate is a severely cold climate that exists mostly on the coastal margins of the Arctic Ocean in extreme northern North America and Eurasia, and along the coast of Greenland. The high-latitude location and proximity to icy water cause every month to have average temperatures below 50 degrees Fahrenheit (10 degrees Celsius), although a few months in summer have means above freezing. As a result of the cold temperatures, tundra areas are not forested, but instead typically have a sparse ground cover of grasses, sedges, flowers, and lichens. Even this vegetation is buried by a layer of snow during most of the year. Cold temperatures lower the water vapor holding capacity of the air, causing precipitation totals to be generally light. Most precipitation is associated with weather fronts and cyclonic storms and occurs during the summer half of the year.

Ice Cap Climate. The most poleward and coldest of the world's climates is called the ice cap climate. It is found on the continent of Antarctica, interior Greenland, and some high mountain peaks and plateaus. Because monthly mean temperatures are subfreezing throughout the year, areas with this climate are glaciated and have no permanent human inhabitants.

The coldest temperatures of all occur in interior Antarctica, where a Russian research station named Vostok recorded the world's coldest temperature of –128.6 degrees Fahrenheit (–89.2 degrees Celsius) on July 21, 1983. This climate receives little precipitation because the atmosphere can hold very little water vapor. A major moisture surplus exists, however, because of the lack of snowmelt and evaporation. This causes the build up of a surface snow cover that eventually compacts to form the icecaps that bury the surface. Snowstorms are often accompanied by high winds, producing blizzard conditions.

Global Warming. Global temperatures increased significantly during the twentieth century. Recordings taken from both ships and land stations indicate that the global average temperature rose by about 0.5 to 1.1 degrees Fahrenheit (0.3 to 0.6 degrees Celsius) during this period, and much of this increase occurred during the 1990's. It is strongly suspected that human activities that increase the abundance of greenhouse gases (heat-trapping gases) in the atmosphere may play a key role in the temperature rise.

Emissions of carbon dioxide, a gas responsible for nearly two-thirds of the global-warming potential of all human-released gases, rose about 400 percent between 1950 and 2000. Carbon dioxide is released chiefly by the burning of fossil fuels. Atmospheric carbon dioxide concentrations are also increased by deforestation, which is occurring at a rapid rate in several tropical countries. Deforestation causes carbon dioxide levels to rise because trees remove large quantities of this gas from the atmosphere during the process of photosynthesis.

Research indicates that if atmospheric concentrations of greenhouse gases continue to increase at the 1990's pace, global temperatures could rise an additional 1.8 to 6.3 degrees Fahrenheit (1 to 3.5 degrees Celsius) during the twenty-first century. That level of temperature increase would produce major changes in global climates and plant and animal habitats and would cause sea levels to rise substantially.

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The World Climate Web site contains temperature and precipitation statistics in both metric and imperial (standard American) units for thousands of worldwide climate-reporting stations, all of which are identified by latitude, longitude, and elevation. Various maps, with enlargement and reduction capabilities, are provided to show the locations of the stations. (www.worldclimate.com/climate/)

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Cloud Formation

Clouds are visible manifestations of water in the air. Cloud patterns can provide even a casual observer with much information about air movements and the processes occurring in the atmosphere. The shapes and heights of the clouds and the directions from which they have come are valuable clues in understanding weather.

Importance of Cooling. Clouds are formed when water vapor in the air is transformed into either water droplets or ice crystals. Sometimes large amounts of moisture are added to the air, producing clouds, but clouds generally are formed when a large amount of air is cooled. The amount of water vapor that air can hold varies with temperature: Cold air can hold less water vapor than warmer air. If air is cooled to the point at

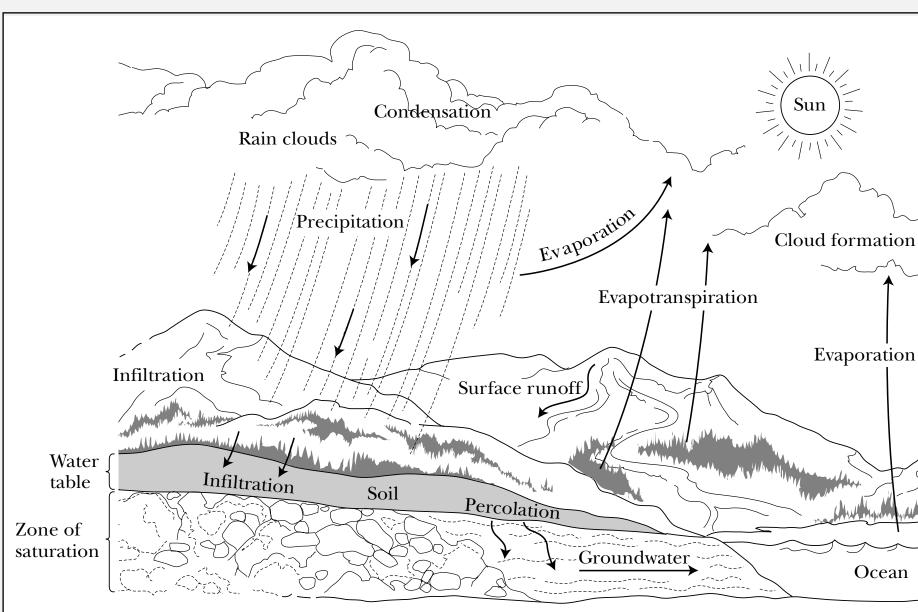
The extent of Earth's cloud cover can be seen in this composite satellite photograph of the planet, on which a portion of northern Mexico and the central United States is the only visible landmass. (PhotoDisc) which it can hold no more water vapor, the water vapor will condense into water droplets. The temperature at which condensation begins is called the dew point. At below freezing temperatures, the water vapor will turn or deposit into ice crystals.

Cloud droplets do not necessarily form even if the air is fully saturated, that is, holding as much water vapor as possible at a given temperature. Once formed, cloud droplets can evaporate again very easily. Two factors hasten the production and growth of cloud droplets. One is the presence of particles in the atmosphere that attract water. These are called hygroscopic particles or condensation nuclei. They include salt, dust, and pollen. Once water vapor condenses on these particles, more condensation can occur. Then the droplets can grow larger and bump into other droplets, growing even larger through this process, called coalescence.

Condensation and cloud droplet growth also is hastened when the air is very cold, at about –40 degrees Fahrenheit (which is also –40 degrees Celsius). At this temperature ice crystals form, but some water droplets can exist as liquid water. These water droplets are said to be supercooled. The water vapor is more likely to deposit on the ice crystals than on the

Cloud Formation

The hydrologic cycle is the continuous circulation of the earth's waters through evaporation, condensation, and precipitation. The cycle also moves water through runoff, infiltration, and transpiration.



Clouds forming over low-lying mountains. (PhotoDisc)

supercooled water. Thus the ice crystals grow larger and the supercooled water droplets evaporate, resulting in more water vapor to deposit on ice crystals. Whether the cloud droplets start as hygroscopic particles or ice crystals, they eventually can grow in size to become a raindrop; around one million cloud droplets make one raindrop.

How and Why Rising Air Cools. In order for air to be cooled, it must rise or be lifted. When a volume of air, or an air parcel, is forced to rise through the surrounding air, the parcel expands in size as the pressure of the air around it declines with altitude. Close to the surface, the atmospheric pressure is relatively high because the density of the atmosphere is high. As altitude increases, the atmosphere declines in density, and the still air exerts less pressure. Thus, as an air parcel rises through the atmosphere, the pressure of the surrounding air declines, and the parcel takes up more space as it expands. Since work is done by the parcel as it expands, the parcel cools and its temperature declines.

An alternative explanation of the cooling is that the number of molecules in the air parcel remains the same, but when the volume is larger, the molecules produce less frictional heat because they do not bang into each other as much. The temperature of the air parcel declines, but no heat leaves the parcel—the change in temperature results from internal processes. The process of an air parcel rising, expanding, and cooling is called adiabatic cooling. Adiabatic means that no heat leaves the parcel. If the parcel rises far enough, it will cool sufficiently to reach its dewpoint

Cumulonimbus clouds are huge, dense formations that rise as high as the stratosphere. Cumulonimbus clouds produce lightning and thunderstorms. (Weather Stock)

temperature. With continued cooling, condensation will result—a cloud will be formed. At this height, which is called the lifting condensation level, an invisible parcel of air will turn into a cloud.

Uplift Mechanisms. An initial force is necessary to cause the air parcel to rise and then cool adiabatically. The three major processes are convection, orographic, and frontal or cyclonic.

With certain conditions, convection or vertical movement can cause clouds to form. On a sunny day, usually in the summer, the ground is heated unevenly. Some areas of the ground become warmer and heat the air above, making it warmer and less dense. A stream of air, called a thermal, may rise. As it rises, it cools adiabatically through expansion and may reach its dew-point temperature. With continued cooling and rising, condensation will occur, forming a cloud. Since the cloud is formed by predominantly vertical motions, the cloud will be cumulus. With continued warming of the surface, the thermals

Types of Clouds

Name	*Altitude (km)*	*Altitude (miles)*
Altocumulus	2-7	6,500-23,000
Altostratus	2-7	6,500-23,000
Cirrocumulus	5-13.75	16,500-45,000
Cirrostratus	5-13.75	16,500-45,000
Cirrus	5-13.75	16,500-45,000
Cumulonimbus	to 2	to 6,500
Cumulus	to 2	to 6,500
Nimbostratus	2-7	6,500-23,000
Stratocumulus	to 2	to 6,500
Stratus	to 2	to 6,500

Source: National Oceanic and Atmospheric Administration.

may rise even higher, perhaps producing thunderstorm, or cumulonimbus, clouds. Thus, a sunny summer day can start off without a cloud in the sky, but can be stormy with many thunderstorms by afternoon.

Clouds also can form when air is forced to rise when it meets a mountain or other large vertical barrier. This type of lifting—orographic—is especially prevalent where air moves over the ocean and then is forced to rise up a mountain, as occurs on the west coast of North and South America. As the air rises, it cools adiabatically and eventually becomes so cool that it cannot hold the water vapor. Condensation occurs and clouds form. The air continues to move up the mountain, producing clouds and precipitation on the side of the mountain from which the wind came, the windward side. However, the air eventually must fall down the other side of the mountain, the leeward side. That air is warmed and moisture evaporates, resulting in no clouds.

A third lifting mechanism is frontal, or cyclonic, action. This occurs when a large mass of cold air and a large mass of warm air—often hundreds of miles in area—meet. The warm air mass and the cold air mass will not mix freely, resulting in a border or front between the two air

The cloud formations seen where tornadoes are developing are known as mammatocumulus. (National Oceanic and Atmospheric Administration) masses. The warm, less dense, air will always rise above the cold, denser, air mass. As the warm air rises, it cools, and when it reaches its dew point, clouds will form. If the warm air displaces the cold air, or a warm front occurs, the warm air will rise gradually, resulting in layered or stratiform clouds. The cloud types will change on an upward diagonal path, with the lowest being stratus, and nimbostratus if rain occurs, followed by altostratus, then cirrostratus, and cirrus.

On the other hand, if the cold air displaces the warm air, the warm air will be forced to rise much more quickly. The clouds formed will be puffy or cumuliform—cumulus at the lowest levels, altocumulus and cirrocumulus at the highest altitudes. Sometimes cumulonimbus clouds will also form.

Sometimes when a cold front meets a warm front, the whole warm air mass is forced off the ground. This forms a cyclone—an area of low pressure—as the warm air rises. As this air rises, it cools. If it reaches its dew point, condensation and clouds will result. In oceanic tropical areas, a cyclone can form within warm, moist air. This air also will cool and, if it reaches its dew point, will condense and form clouds. Sometimes, these tropical cyclones are the precursors of hurricanes. The clouds associated with cyclones are usually cumulus, including cumulonimbus, as they are formed by rapidly rising air.

Margaret F. Boorstein

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(ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/cld/home.rxml)

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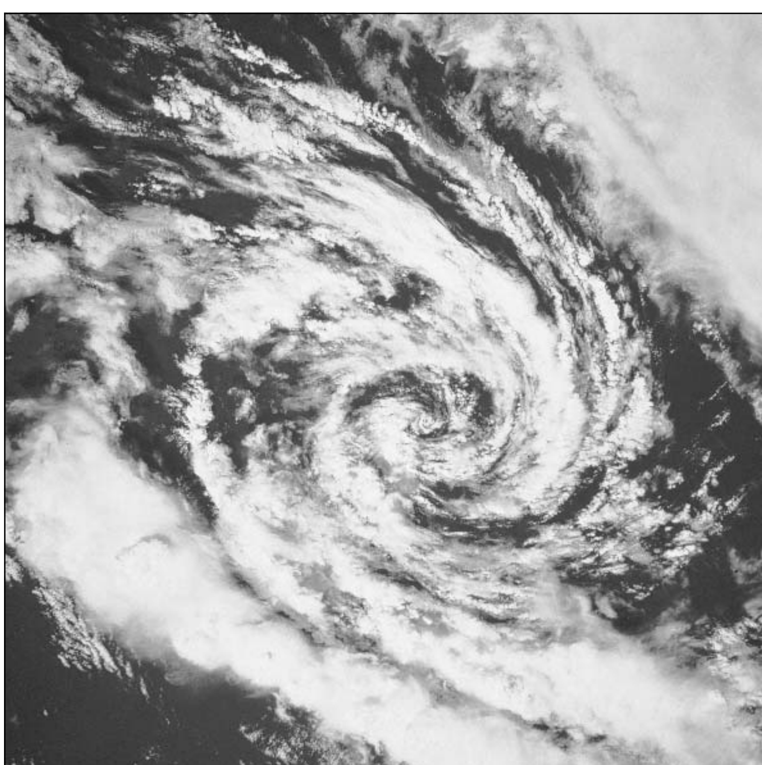
Storms

A storm is an atmospheric disturbance that produces wind, is accompanied by some form of precipitation, and sometimes involves thunder and lightning. Storms that meet certain criteria are given specific names, such as hurricanes, blizzards, and tornadoes.

Stormy weather is associated with low atmospheric pressure, while

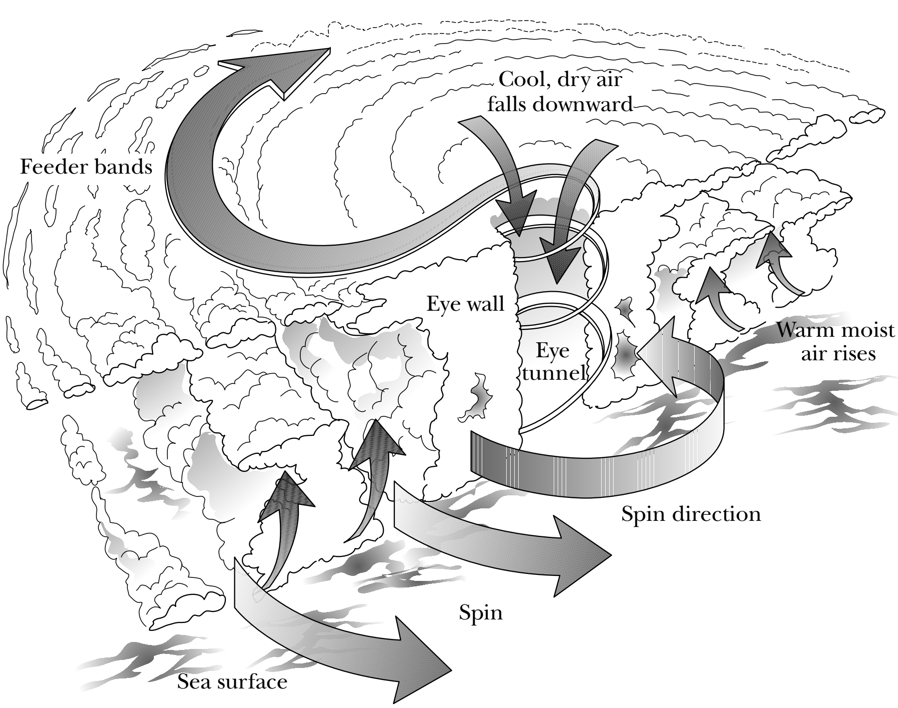


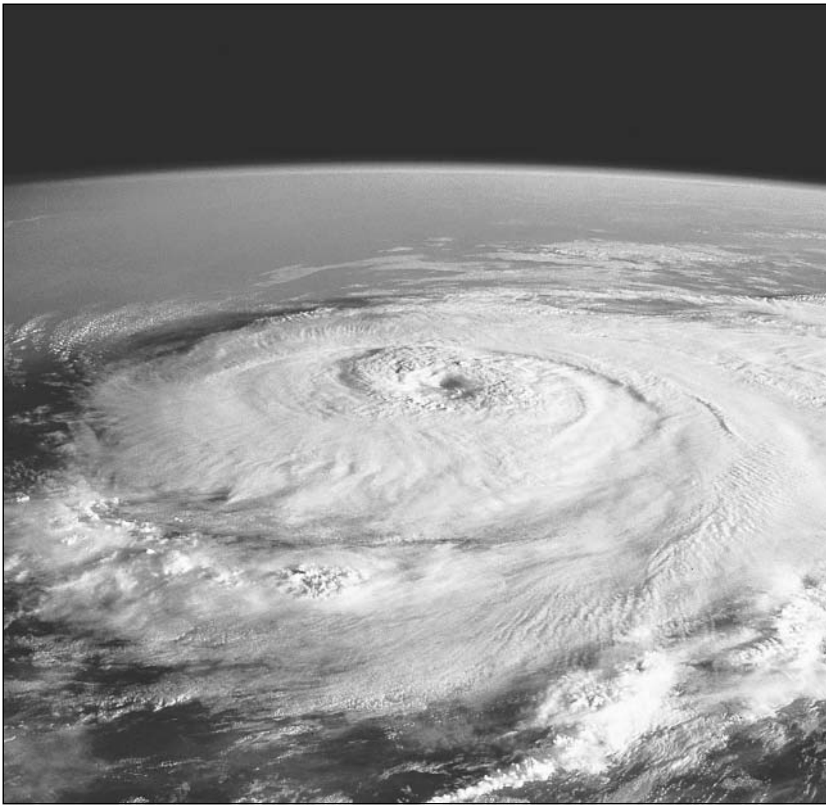
Satellite view of a hurricane. (PhotoDisc) clear, calm, dry weather is associated with high atmospheric pressure. Because of the way atmospheric pressure and wind direction are related, low-pressure areas are characterized by winds moving cyclonically (in a counterclockwise direction in the Northern Hemisphere; clockwise in the Southern Hemisphere) around the center of the low pressure. Storms of all kinds are associated with cyclones, but two classes of cyclones—tropical and extratropical—produce most storms.

Tropical Cyclones. These storms develop during the summer and autumn in every tropical ocean except the South Atlantic and eastern South Pacific Oceans. Tropical cyclones that occur in the North Atlantic and eastern North Pacific Oceans are known as hurricanes; in the western North Pacific Ocean, as typhoons; and in the Indian and South Pacific Oceans, as cyclones.

All tropical cyclones develop in three stages. Arising from the formation of the initial atmospheric disturbance that is characterized by a cluster of thunderstorms, the first stage—tropical depression—occurs when the maximum sustained surface wind speeds (the average speed over one minute) range from 23-39 miles (37-61 km.) per hour. The second stage—tropical storm—occurs when sustained winds range from 40-73 miles (62-119 km.) per hour. At this stage, the storm is given a name.

Anatomy of a Hurricane





The eye of this hurricane is clearly visible at the storm's center. (PhotoDisc)

From eighty to one hundred tropical storms develop each year across the world, with about half continuing to the final stage—hurricane—at which sustained wind speeds are 74 miles (120 km.) per hour or greater. Moving over land or into colder oceans initiates the end of the hurricane after a week or so by eliminating the hurricane's fuel—warm water.

A mature hurricane is a symmetrical storm, with the "eye" at the center; the eye develops as winds increase and become circular around the central core of low pressure. Within the eye, it is relatively warm, and there are light winds, no precipitation, and few clouds. This is caused by air descending in the center of the storm. Surrounding the eye is the "eye wall," a ring of intense thunderstorms that can extend high into the atmosphere. Within the eye wall, the strongest winds and heaviest rainfall are found; this is also where warm, moist air, the hurricane's "fuel," flows into the storm. Spiraling bands of clouds, called "rain bands," surround the eye wall. Precipitation and wind speeds decrease from the eye wall out toward the edge of the rain bands, while atmospheric pressure is lowest in the eye and increases outward.

The immense strength of hurricane winds makes hurricanes the most damaging type of storm system. (PhotoDisc)

Hurricanes can be the most damaging storms because of their intensity and size. Damage is caused by high winds and the flying debris they carry, flooding from the tremendous amounts of rain a hurricane can produce, and storm surge. A storm surge, which accounts for most of the coastal property loss and 90 percent of hurricane deaths, is a dome of water that is pushed forward as the storm moves. This wall of water is lifted up onto the coast as the eye wall comes in contact with land. For example, a 25-foot (8-meter) storm surge created by Hurricane Camille in 1969 destroyed the Richelieu Apartments next to the ocean in Pass Christian, Mississippi. Ignoring advice to evacuate, twenty-five people had gathered there for a hurricane party; all but one was killed.

To help predict the damage that an approaching hurricane can cause, the Saffir-Simpson Scale was developed. A hurricane is rated from 1 (weak) to 5 (devastating), according to its central pressure, sustained wind

Naming Hurricanes

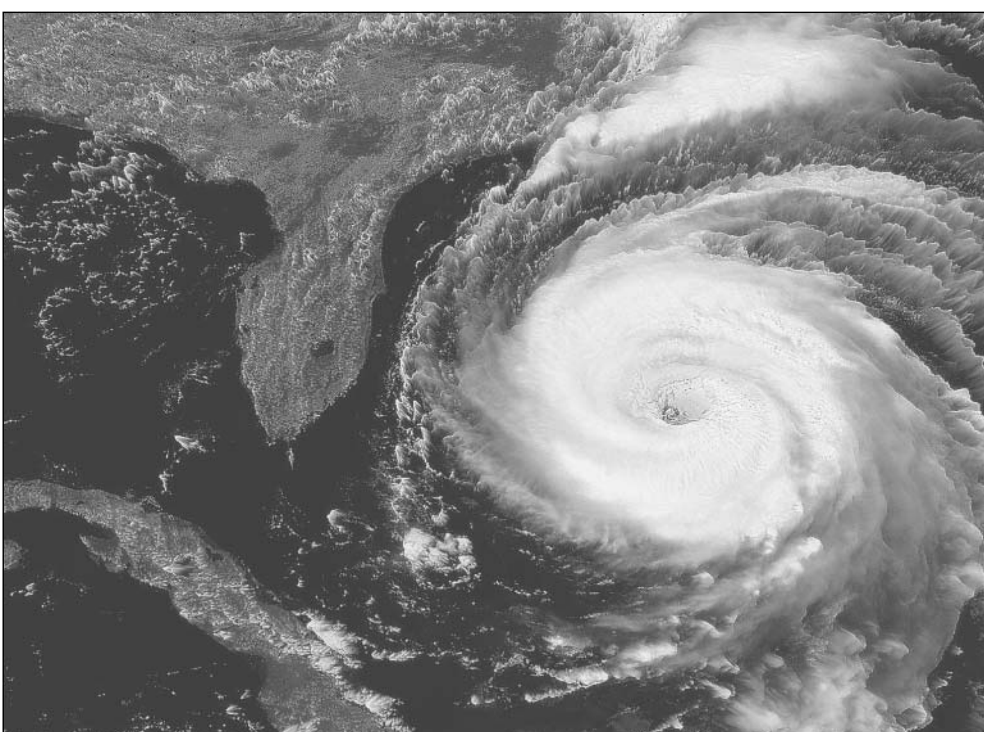
Hurricanes once were identified by their latitudes and longitudes, but this method of naming became confusing when more than one hurricane developed at the same time in the same ocean. During World War II hurricanes were identified by radio code letters, such as “Able” and “Baker.” In 1953 the National Weather Service began using English female names in an alphabetical list. Male names and French and Spanish names were added in 1978. By 2000 six lists of names were used on a rotating basis. When a particular hurricane causes much death or destruction, as Hurricane Andrew did in August of 1992—its name is retired for at least ten years.

speed, and storm surge height. Camille (1969) was a Category 5 and Andrew (1992) was a Category 4.

Extratropical Cyclones. Also known as midlatitude cyclones, these storms are traveling low-pressure systems that are seen on newspaper and television daily weather maps. They are created when a mass of moist, warm air from the south contacts a mass of drier, cool air from the north, causing a front to develop. At the front, the warmer air rides up over the colder air. This causes water vapor to condense and produces clouds and rain during most of the year, and snow in the winter.

Thunderstorms. Thunderstorms also develop in stages. During the cumulus stage, strong updrafts of warm air build the storm clouds. The storm moves into the mature stage when updrafts continue to feed the storm, but cool downdrafts are also occurring in a portion of the cloud where precipitation is falling. When the warm updrafts disappear, the storm's fuel is gone and the dissipating stage begins. Eventually, the cloud rains itself out and evaporates.

Thunderstorms can also form away from a frontal system, usually during summer. This formation is related to a relatively small area of warm, moist air rising and creating a thunderstorm that is usually localized and short lived.



The immense size that a hurricane can reach is dramatically evident in this satellite image of a hurricane off the coasts of Florida and Cuba. (PhotoDisc)

Lightning storm over Seattle, Washington. Lightning is the product of positive and negative electrical charges in storm clouds creating giant sparks while attempting to balance out. Lightning that finds its way to the surface heats the air around it to such high temperatures that the air expands explosively, creating the shock waves called thunder. (PhotoDisc)

Wind, lightning, hail, and flooding from heavy rain are the main destructive forces of a thunderstorm. Lightning occurs in all mature thunderstorms as the positive and negative electrical charges in a cloud attempt to equal out, creating a giant spark. Most lightning stays within the clouds, but some finds its way to the surface. The lightning heats the air around it to incredible temperatures (54,000 degrees Fahrenheit/30,000 degrees Celsius), which causes the air to expand explosively, creating the shock wave called thunder. Since lightning travels at the speed of light and thunder at the speed of sound, one can estimate how many miles away the lightning is by counting the seconds between the lightning and thunder and dividing by five. People have been killed by lightning while boating, swimming, biking, golfing, standing under a tree, talking on the telephone, and riding on a lawnmower.

Hail is formed in towering cumulonimbus clouds with strong updrafts. It begins as small ice pellets that grow by collecting water droplets that freeze on contact as the pellets fall through the cloud. The strong updrafts push the pellets back into the cloud, where they continue collecting water droplets until they are too heavy to stay aloft and fall as hailstones. The more an ice pellet is pushed back into the cloud, the larger the hailstone becomes. The largest authenticated hailstone in the United States fell on Coffeyville, Kansas, in September, 1970. It weighed 1.67 pounds (757 grams) and was 5.5 inches (14 centimeters) in diameter.

Tornadoes. For reasons not well understood, less than 1 percent of all thunderstorms spawn tornadoes. Called funnel clouds until they touch earth, tornadoes contain the highest wind speeds known.

Although tornadoes can occur anywhere in the world, the United States has the most, with an average of eight hundred per year. Tornadoes have occurred in every state, but the greatest number hit a portion of the Great Plains from central Texas to Nebraska, known as "Tornado Alley." There cold, Canadian air and warm, Gulf Coast air often collide over the flat land, creating the wall cloud from which most tornadoes are spawned. May is the peak month for tornado activity, but they have been spotted in every month.

Because tornado winds cannot be measured directly, the tornado is ranked according to its damage, using the Fujita Intensity Scale. The scale ranges from an F0, with wind speeds less than 72 miles (116 km.) per hour, causing light damage, to an F5, with winds greater than 260 miles (419 km.) per hour, causing incredible damage. Most tornadoes are small, but the larger ones cause much damage and death.

Kay R. S. Williams

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The Weather page at *USA Today*'s Web site features up-to-date national and world weather information, maps, and forecasts, as well as articles on weather-related topics, an interactive question-and-answer feature, and current information on hurricanes and tornadoes.
(www.usatoday.com/weather/)

The Weather Channel's Web site, Weather.Com, features up-to-date national and world weather information, maps, and forecasts. The "Learn More" link directs viewers to the Weather Classroom, an educational series exploring weather science, with teacher and student resources, backyard projects, and severe weather safety information. (www.weather.com)

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BIOGEOGRAPHY AND NATURAL RESOURCES

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Earth's Biological Systems

Biomes

The major recognizable life zones of the continents, biomes are characterized by their plant communities. Temperature, precipitation, soil, and length of day affect the survival and distribution of biome species. Species diversity within a biome may increase its stability and capability to deliver natural services, including enhancing the quality of the atmosphere, forming and protecting the soil, controlling pests, and providing clean water, fuel, food, and drugs. Land biomes are the temperate, tropical, and boreal forests; tundra; desert; grasslands; and chaparral.

Temperate Forest. The temperate forest biome occupies the so-called temperate zones in the midlatitudes (from about 30 to 60 degrees north and south of the equator). Temperate forests are found mainly in Europe, eastern North America, and eastern China, and in narrow zones on the coasts of Australia, New Zealand, Tasmania, and the Pacific coasts of North and South America. Their climates are characterized by high rainfall and temperatures that vary from cold to mild.

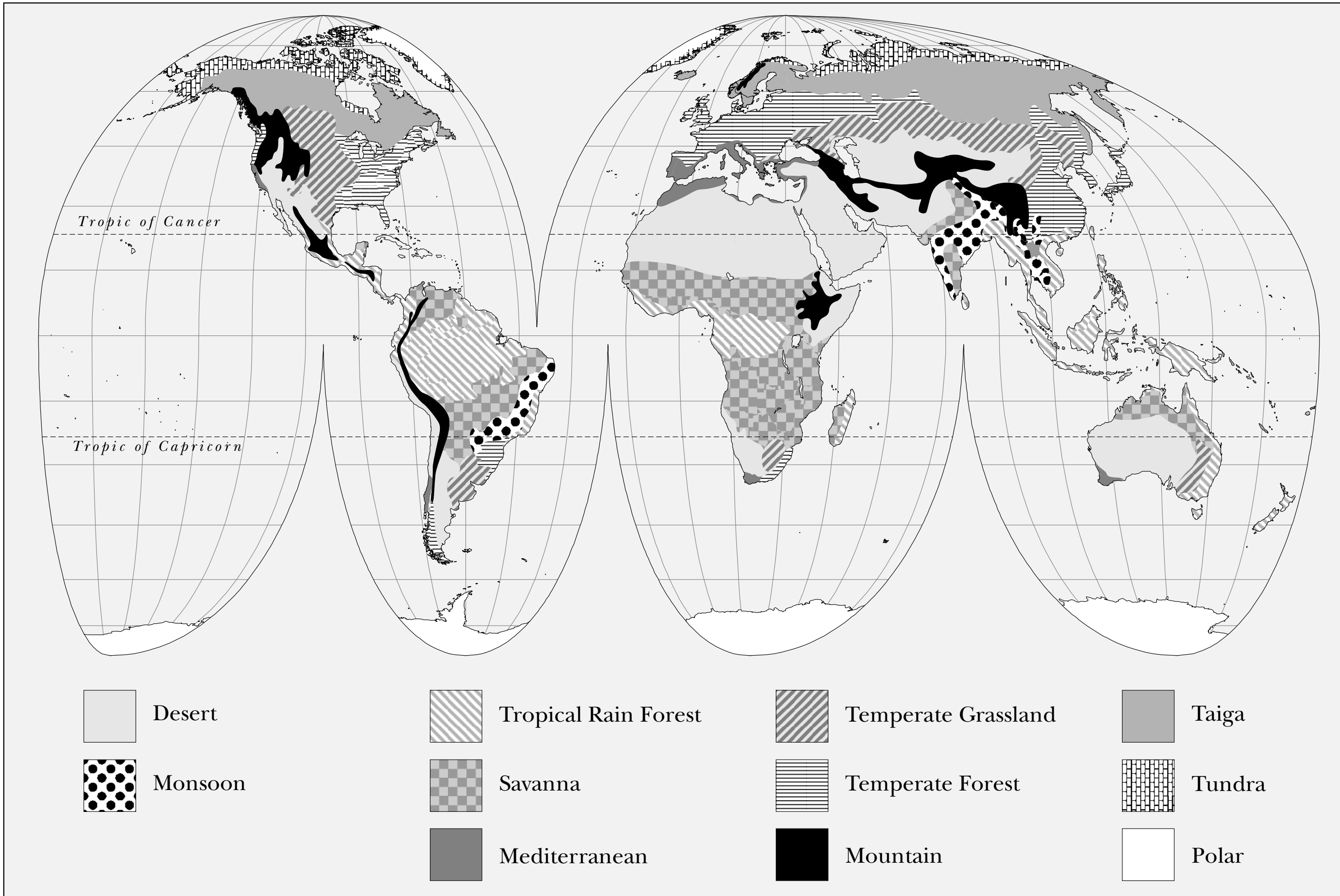
Temperate forests contain primarily deciduous trees—including maple, oak, hickory, and beechwood—and, secondarily, evergreen trees—including pine, spruce, fir, and hemlock. Evergreen forests in some parts of the Southern Hemisphere contain eucalyptus trees.

The root systems of forest trees help keep the soil rich. The soil quality and color is due to the action of earthworms. Where these forests are frequently cut, soil runoff pollutes streams, which reduces fisheries because of the loss of spawning habitat. Racoons, opposums, bats, and squirrels are found in the trees. Deer and black bear roam forest floors. During winter, small animals such as groundhogs and squirrels burrow in the ground.

Tropical Forest. Tropical forests are in frost-free areas between the Tropic of Cancer and the Tropic of Capricorn. Temperatures range from warm to hot year-round, because the Sun's rays shine nearly straight down around midday. These forests are found in northern Australia, the East Indies, southeastern Asia, equatorial Africa, and parts of Central America and northern South America.

Tropical forests have high biological diversity and contain about 15 percent of the world's plant species. Animal life lives at different layers of tropical forests. Nuts and fruits on the trees provide food for birds, monkeys, squirrels, and bats. Monkeys and sloths feed on tree leaves. Roots, seeds, leaves, and fruit on the forest floor feed deer, hogs, tapirs, ante-

Biomes of the World



The aspen is a deciduous tree that is well adapted to cold winters in boreal forests. (PhotoDisc)

lopes, and rodents. The tropical forests produce rubber trees, mahogany, and rosewood. Large animals in these forests include the Asian tiger, the African bongo, the South American tapir, the Central and South American jaguar, the Asian and African leopard, and the Asian axis deer. Deforestation for agriculture and pastures has caused reduction in plant and animal diversity.

Boreal Forest. The boreal forest is a circumpolar Northern Hemisphere biome spread across Russia, Scandinavia, Canada, and Alaska. The region is very cold. Evergreen trees such as white spruce and black spruce dominate this zone, which also contains larch, balsam, pine, and fir, and some deciduous hardwoods such as birch and aspen. The acidic needles from the evergreens make the leaf litter that is changed into soil humus. The acidic soil limits the plants that develop.

Animals in boreal forests include deer, caribou, bear, and wolves. Birds in this zone include goshawks, red-tailed hawks, sapsuckers, grouse, and nuthatches. Relatively few animals emigrate from this habitat during winter. Conifer seeds are the basic winter food. The disappearing aspen habi-

Wetlands, places where the ground is saturated with water, constitute transition zones between aquatic ecosystems and terrestrial ecosystems. (PhotoDisc)

tat of the beaver has decreased their numbers and has reduced the size of wetlands.

Tundra. About 5 percent of the earth's surface is covered with Arctic tundra, and 3 percent with alpine tundra. The Arctic tundra is the area of Europe, Asia, and North America north of the boreal coniferous forest zone, where the soils remain frozen most of the year. Arctic tundra has a permanent frozen subsoil, called permafrost. Deep snow and low temperatures slow the soil-forming process. The area is bounded by a 50 degrees Fahrenheit circumpolar isotherm, known as the summer isotherm. The cold temperature north of this line prevents normal tree growth.

The tundra landscape is covered by mosses, lichens, and low shrubs, which are eaten by caribou, reindeer, and musk oxen. Wolves eat these herbivores. Bear, fox, and lemming also live here. The larger mammals, including marine mammals and the overwintering birds, have large fat layers beneath the skin and long dense fur or dense feathers that provide protection. The small mammals burrow beneath the ground to avoid the harsh winter climate. The most common Arctic bird is the old squaw duck. Ptarmigans and eider ducks are also very common. Geese, falcons, and loons are some of the nesting birds of the area.

The alpine tundra, which exists at high altitude in all latitudes, is acted upon by winds, cold temperatures, and snow. The plant growth is mostly cushion and mat-forming plants.

Desert. The desert biome covers about one-seventh of the earth's surface. Deserts typically receive no more than 10 inches (25 centimeters) of rainfall a year, but evaporation generally exceeds rainfall. Deserts are found around the Tropic of Cancer and the Tropic of Capricorn. As the warm air rises over the equator, it cools and loses its water content. This dry air descends in the two subtropical zones on each side of the equator; as it warms, it picks up moisture, resulting in drying the land.

Rainfall is a key agent in shaping the desert. The lack of sufficient plant cover removes the natural protection that prevents soil erosion during storms. High winds also cut away the ground.

Some desert plants obtain water from deep below the surface, for example, the mesquite tree, which has roots that are 40 feet (13 meters) deep. Other plants, such as the barrel cactus, store large amounts of water in their leaves, roots, or stems. Other plants slow the loss of water by having tiny leaves or shedding their leaves. Desert plants have very short growth periods, because they cannot grow during the long drought periods.

Desert animals protect themselves from the Sun's heat by eating at night, staying in the shade during the day, and digging burrows in the ground. Among the world's large desert animals are the camel, coyote, mule deer, Australian dingo, and Asian saiga. The digestive process of some desert animals produces water. A method used by some animals to conserve water is the reabsorption of water from their feces and urine.

Grassland. Grasslands cover about a quarter of the earth's surface, and can be found between forests and deserts. Treeless grasslands grow in parts of central North America, Central America, and eastern South America that have between 10 and 40 inches (250-1,000 millimeters) of erratic rainfall. The climate has a high rate of evaporation and periodic major droughts. The biome is also subject to fire.

Some grassland plants survive droughts by growing deep roots, while others survive by being dormant. Grass seeds

Barrel cactus. (Digital Stock)

feed the lizards and rodents that become the food for hawks and eagles. Large animals include bison, coyotes, mule deer, and wolves. The grasslands produce more food than any other biome. Poor grazing and agricultural practices and mining destroy the natural stability and fertility of these lands. The reduced carrying capacity of these lands causes an increase in water pollution and erosion of the soil. Diverse natural grasslands appear to be more capable of surviving drought than are simplified manipulated grass systems. This may be due to slower soil mineralization and nitrogen turnover of plant residues in the simplified system.

Savannas are open grasslands containing deciduous trees and shrubs. They are near the equator and are associated with deserts. Grasses grow in clumps and do not form a continuous layer. The northern savanna bushlands are inhabited by oryx and gazelles. The southern savanna supports springbuck and eland. Elephants, antelope, giraffe, zebras, and black rhinoceros are found on the savannas. Lions, leopards, cheetah, and hunting dogs are the primary predators here. Kangaroos are found in the savannas of Australia. Savannas cover South America north and south of the Amazon rain forest, where jaguar and deer can be found.

Mediterranean. The Mediterranean biome is found in the Mediterranean Basin, California, southern Australia, middle Chile, and Cape Province of South Africa. In California it is known as chaparral. This region has a climate of wet winters and summer drought. The plants have tough leathery leaves and may contain thorns. Regional fires clear the area of dense and dead vegetation. Fire, heat, and drought shape the region. The vegetation dwarfing is due to the severe drought and extreme climate changes. The seeds from some plants, such as the California manzanita and South African fire lily, are protected by the soil during a fire and later germinate and rapidly grow to form new plants.

Ocean. The ocean biome covers more than 70 percent of the earth's surface and includes 90 percent of its volume. The ocean has four zones. The intertidal zone is shallow and lies at the land's edge. The continental shelf, which begins where the intertidal zone ends, is a plain that slopes gently seaward. The neritic zone (continental slope) begins at a depth of about 600 feet (180 meters), where the gradual slant of the continental shelf becomes a sharp tilt toward the ocean floor, plunging about 12,000 feet (3,660 meters) to the ocean bottom, which is known as the abyss. The abyssal zone is so deep that it does not have light.

Plankton are animals that float in the ocean. They include algae and copepods, which are microscopic crustaceans. Jellyfish and animal larva are also considered plankton. The nekton are animals that move freely through the water by means of their muscles. These include fish, whales, and squid. The benthos are animals that are attached to or crawl along the ocean's floor. Clams are examples of benthos. Bacteria decompose the dead organic materials on the ocean floor.

The circulation of materials from the ocean's floor to the surface is

Beaver dams are becoming less common as the wetlands they inhabit are giving way to human settlements. (PhotoDisc)

caused by winds and water temperature. Runoff from the land contains polluting chemicals such as pesticides, nitrogen fertilizers, and animal wastes. Rivers carry loose soil to the ocean, where it builds up the bottom areas. Overfishing has caused fisheries to collapse in every world sector. In some parts of the northwestern Altantic Ocean, there has been a shift from bony fish to cartilaginous fish dominating the fisheries.

Human Impact on Biomes. Human interaction with biomes has increased biotic invasions, reduced the numbers of species, changed the quality of land and water resources, and caused the proliferation of toxic compounds. Managed care of biomes may not be capable of undoing these problems.

Ronald J. Raven

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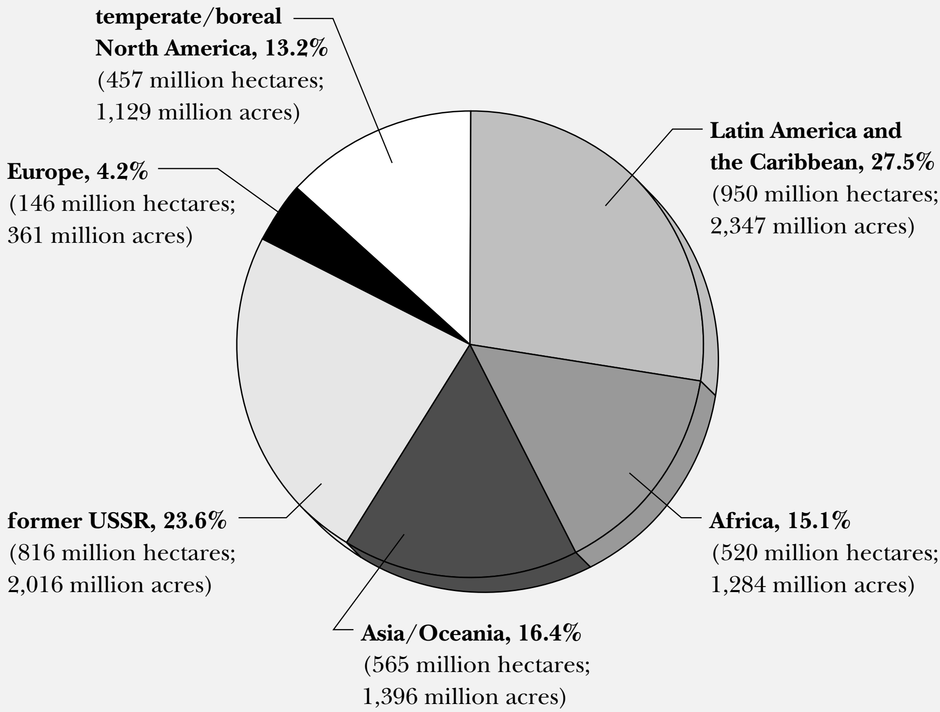
Forests

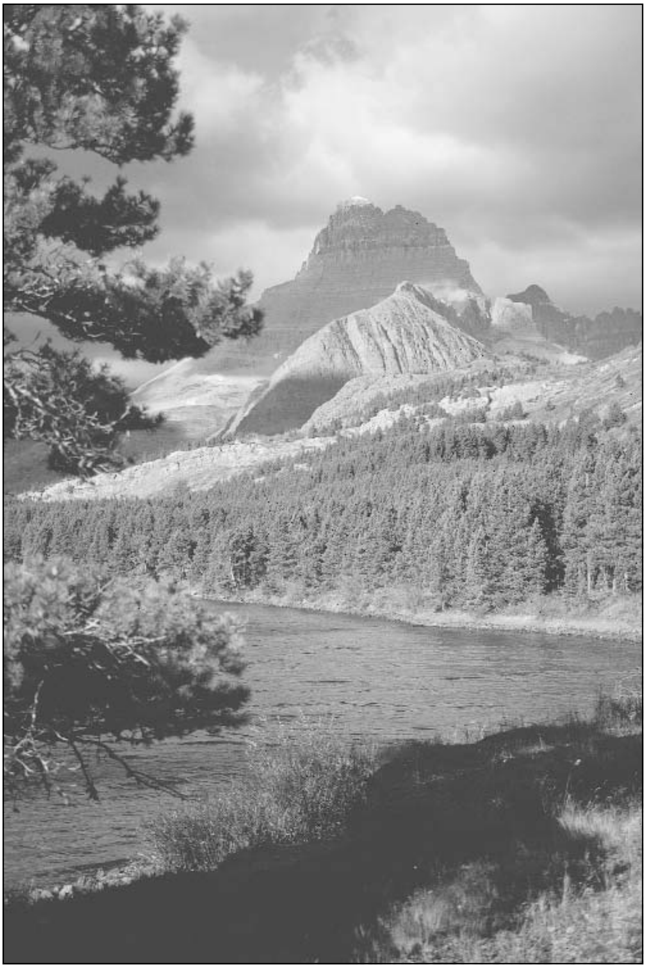
Extending over 25 percent of the earth's land surface, forests are the world's most complex, productive, and diverse terrestrial communities. The most conspicuous plants of these ecosystems are trees. Trees are tall, woody plants that have one main stem (trunk) and a well-developed crown consisting of branches and leaves. Coniferous trees have narrow needle- or scale-like evergreen leaves and bear their seeds in cones. Flowering angiosperm trees produce seeds in a fruit, nut, or pod. They

Forest Areas by Main Regions in 1995



1995: total area = 3,454 million hectares; 8,531 million acres

Source: United Nations Food and Agriculture Organization (FAOSTAT Database, 2000).



Evergreen forest in Glacier National Park. (PhotoDisc)

are of both evergreen broadleaf and deciduous broadleaf form. Evergreen broadleafs predominate where warm, moist conditions persist throughout the year. Deciduous trees drop their leaves in fall where adequate soil moisture is seasonally unavailable.

Numerous plants and animals coexist with trees in one or more of the canopy, shrub, herbaceous, or ground layers. The great degree of layering, or stratification, in forests produces a great variety of environmental conditions and habitat types, which promote a high diversity of animal species. The presence of photosynthesizing plants across many layers also assures high production of food for wildlife.

Forests are the natural vegetation of humid climates whose temperatures remain above 50 degrees Fahrenheit (10 degrees Celsius) for at least one month of each year. Forest communities are classified based on

Washington's Olympic National Park contains a well-known example of a temperate-zone rain forest. (Digital Stock)

their adaptation to particular climates and soils. Temperate-zone rain forests, composed of large coniferous trees, occur in cool climates that remain above freezing and receive abundant rainfall. Tropical deciduous forests are found just outside the equatorial region, where a pronounced dry season prompts leaf fall. Global forest zones may begin shifting toward the poles in this century in response to climate warming.

Tropical Rain Forests. Covering about 7 percent of the world's land area, tropical rain forests are home to more than half the world's species. These communities are found at low elevations in the Amazon Basin of South America, the Congo Basin of Africa, and in Southeast Asia. Moisture and energy are abundant, but competition for light produces a well-developed layering of forest plants. Broadleaf evergreens dominate in the three canopy layers. Well-spaced, umbrella-shaped emergents soar high above the forest floor. Beneath, the main canopy contains a tremendous variety of closely spaced trees.

Although about 80 percent of the Sun's energy is absorbed in the upper layer of the rain forest, a subcanopy of slender trees and saplings survives in the shade below. Woody vines, or lianas, climb trees, competing for light in the canopy. The strangler fig emerges from a seed in the canopy and sends down roots to the ground. The roots thicken and engulf the host tree, which eventually is cut off from light and dies. After it decays, a hollow is left where the tree once stood. Epiphytic plants attach to canopy branches and obtain nutrients from the air or dead plant material fallen on them. Epiphytic bromeliads store up to two gallons of rainwater in their cup-like arrangement of leaves, providing rearing grounds for tadpoles of the poison arrow frog.

Having the most available foliage, the canopy is the most populated area of the forest. Arboreal mammals, reptiles, birds, amphibians, and insects are highly adapted to living in the canopy. Parrots use their beaks and claws to move from branch to branch. Fruit bats fly easily through the canopy. The long, grasping hands and feet of many primates help locomotion through trees. Many New World monkeys have evolved prehensile tails that serve as a fifth grasping limb and help them maintain balance.

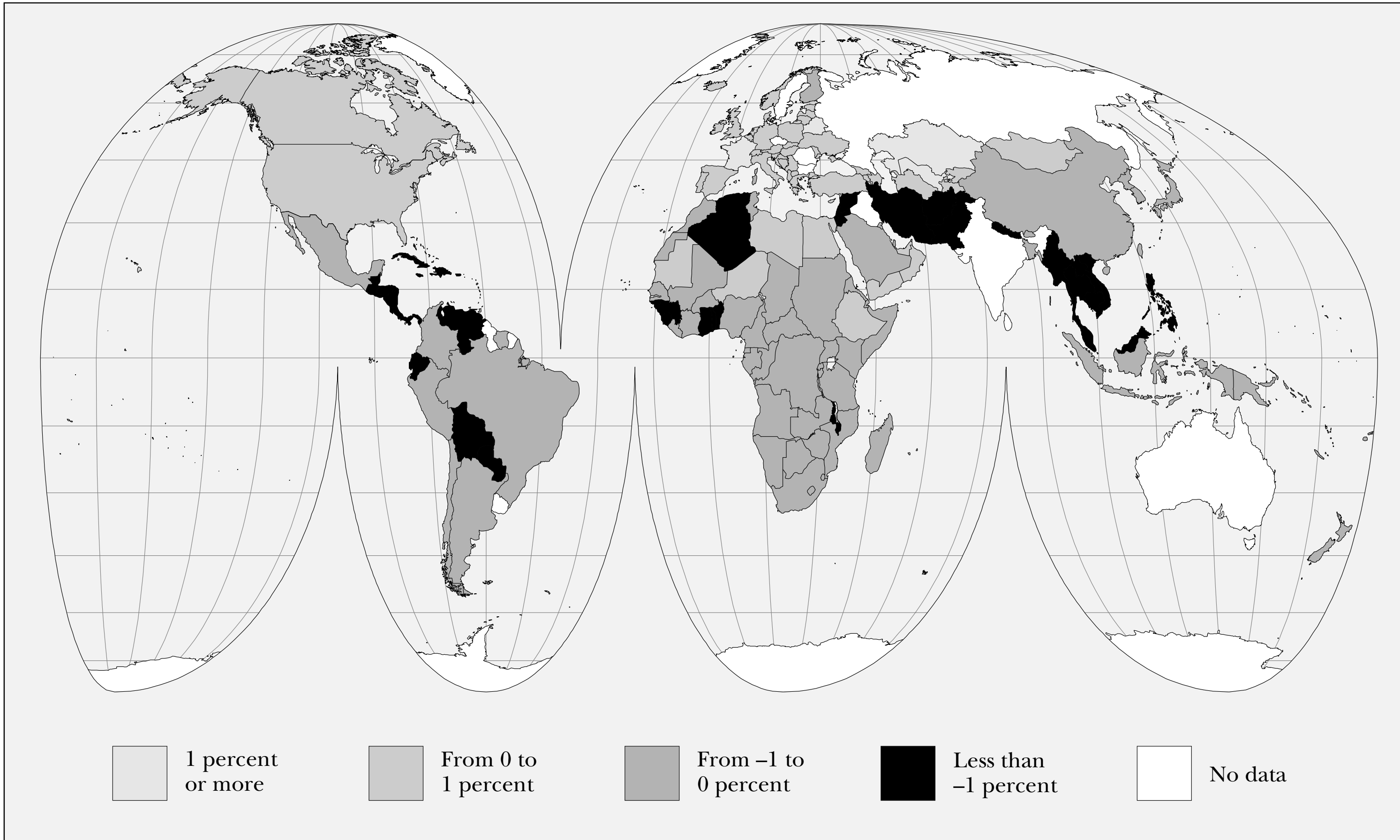
Little light penetrates to the forest floor. Herbaceous plants possess large leaves to maximize energy reception, but are sparse. Many leaves have pointed tips to drain water and prevent fungal attack. Jaguars, bush dogs, ocelots, tapirs, ants, termites, coral snakes, and pit vipers are found on the floor of the Brazilian rain forest. Tree bases have protruding edges for support of the tall trees, and roots lie close to the soil surface to absorb nutrients from decaying vegetation. This is important since the old, weathered soils are nutrient poor.

Tropical Plants: Going, Going . . . Gone?

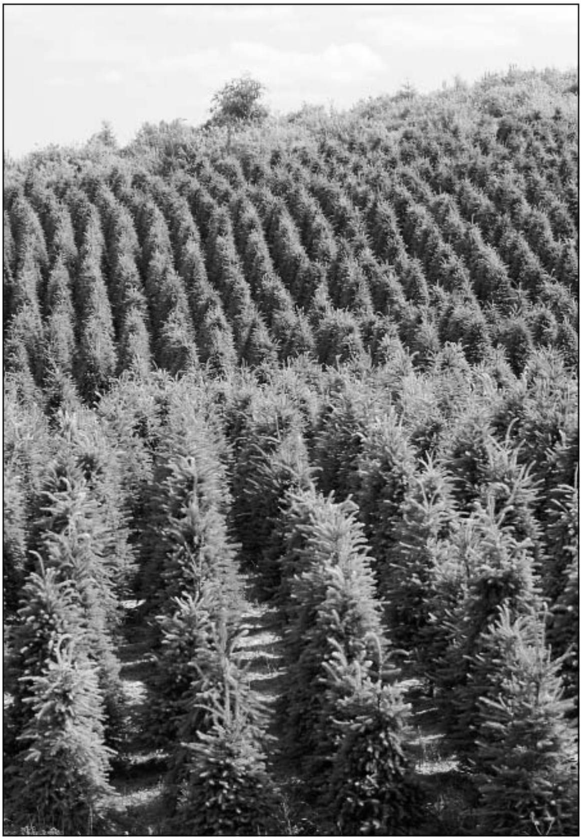
Tropical plants are of great importance to economies worldwide. Teak, mahogany, ebony, and rosewood are used to make furniture. Brazil nuts, mangos, bananas, and breadfruit are important foods for both tropical and nontropical peoples. The rosy periwinkle of Madagascar is used to treat a rare form of leukemia. Thousands of other plants have been identified as containing possible cancer-fighting chemicals. Perhaps most importantly, tropical plants contribute to the earth's life support systems by providing clean air, preventing climate change, storing water, and preserving biodiversity.

Despite these valuable contributions, 56,000 square miles (145,000 sq. km.) of tropical forest—an area the size of Iowa—is cut down annually, and even more is fragmented or degraded. Commercial logging, plantation and small farm agriculture, cattle ranching, and mining are the main agents of destruction to tropical forests, a large amount of which will be lost within decades at the current rate of development.

PERCENTAGE OF ANNUAL DEFORESTATION BY COUNTRY, 1990-1995



Source: United Nations Food and Agriculture Organization.



Tree farming has become an important method of replenishing the world's diminishing forest resources. (PhotoDisc)

Midlatitude Broadleaf Deciduous and Boreal Coniferous Forests. Midlatitude forests are found between about 30 and 60 degrees north and south of the equator, and face many climate perils. Broadleaf deciduous forests receive ample precipitation throughout the year, but must survive winter freezes when soil moisture becomes unavailable. The predominant trees, such as oak, maple, and cherry, shed their leaves in autumn to prevent dehydration. Beautiful displays of colors occur when green chlorophyll production stops before the leaves fall. The remaining pigments (anthocyanins, carotinoids), which were always present in the leaf, then become visible.

In contrast, subarctic boreal forests consist of needle-leaf conifers, including spruces, firs, and pines. The conical-shaped trees easily shed snow, and the small surface area of the needles reduces moisture loss. Few deciduous trees grow here, since the short growing season provides insufficient energy for both growth and regeneration of leaves. Evergreens begin growing early in spring, giving them an advantage over deciduous trees.

Compared to tropical forests, midlatitude forests show less species diversity and reduced layering of vegetation. Boreal forests have only one main canopy, and a single moss, lichen, and grass layer. Rain forests have hundreds of tree species in a small area, while boreal forests are dominated by large numbers of few species.

Similar types of animal life are found in both of these forests. In North America, grizzly and black bears, bobcats, lynxes, cougars, wolves, and foxes exist where humans have not driven them out. Deer, raccoons, squirrels, rabbits, and skunks are common. Migratory birds, retreating in winter to warmer areas with more food, are attracted back by the numerous insects and fruit which reappear seasonally. Numerous adaptations, such as hibernation, food switching, and thick, wind-resistant fur aid survival during long, cold winters.

Kathleen V. Schreiber

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The Environmental Literacy Council is a nonprofit organization of scientists, economists, educators, and other experts informing environmental studies. The council's Web site provides links to a wide range of forest topics. (www.enviroliteracy.org/subcategory.php/20.html)

National Geographic magazine's on-line article "Congo Trek: A Journey Through the Heart of Central Africa" documents biologists' 1,200-mile hike through tropical African forest with photos and field notes. (www.nationalgeographic.com/congotrek)

Educational Web Adventures' "Amazon Interactive" site explores the geography of the Amazonian rain forest through games and activities. (www.eduweb.com/amazon.html)

Resources for the Future, a nonprofit and nonpartisan organization based in Washington, D.C., conducts independent research on environmental and natural resource issues. A section of the organization's on-line Natural Resources Library focuses on the impacts of climate change on forests. (www.rff.org/nat_resources/forests.htm)

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Grasslands

Grasslands cover about a quarter of the world's land surface. Since they grow on the world's richest soils, they are so intensely farmed and grazed that only small patches of natural grassland remain.

Climate and Geographic Location. Annual precipitation between 10 and 32 inches (25-80 centimeters), often with a dry period late in the growing season, supports grassland. Grassland temperature patterns vary. Fire and grazing favor grasses and often combine with climate to maintain grasslands.

Extensive grasslands generally are found in continental interiors. In North America, grasslands occur from the eastern foothills of the Rocky Mountains to the Mississippi River, from south central Canada to northeastern Mexico, in eastern Washington and Oregon, and in California's Central Valley. Grasslands on other continents include the steppes of Europe and Asia, areas fringing the major deserts of Africa and Australia, and the Pampas of South America.

Types of Grasslands. Extensive grasslands are often divided into tall-grass, mixed-grass, and short-grass regions. In pre-human-settlement North American grasslands, the tall-grass prairie occurred in the moist eastern zone. Big bluestem, Indian grass, and switch grass grew 6-10 feet (2-3 meters) tall in this region. The short-grass prairie or plains occupied the drier western extreme. Here, blue grama and buffalo grass seldom grew taller than 8 inches (20 centimeters). Mixed-grass prairie grew in between, with a mixture of tall, short, and middle-height grasses. Boundaries between regions were broad zones of gradual change.

Grasses and Grasslands. Grasses are well adapted to occupy regions with intermediate annual precipitation, fires, and grazing animals. Grasses have their main center of growth at or below the ground. Their slender, widespread roots compete intensely for nutrients and moisture, especially near the surface. The above-ground parts of the plants grow densely, and the entire above-ground plant dies every year, covering the ground with a dense mulch. This combination presents difficulties for plants invading grasslands, as the grass roots usurp moisture and nutrients and the leaves and mulch intercept sunlight.

Under very dry conditions, when grasses cannot grow densely, shrubs and succulents (such as cacti) dominate and deserts occur. With heavy rainfall and infrequent dry periods, trees compete well with grasses, and forests dominate the landscape. Grasslands are often bordered by forests at their moist edges and deserts at their dry boundaries. Under intermediate rainfall conditions, however, grasses are favored over all competitors.

Fire and grazing by animals tip the balance further in favor of the grasses. The late-season dry period typical of grasslands and the mulch

The great herds of buffalo that once roamed North America's plains played an important role in maintaining the native grasslands. (PhotoDisc)

North American Grassland Grazers

Bison numbered in the millions in presettlement North American grasslands and were the center of the economies of the Plains Indians. Pronghorns may have been even more numerous than bison. Both wandered widely over the prairies and plains and undoubtedly had a great impact on plant life.

Prairie dogs are smaller and less mobile but within their "towns" they may have had an even greater impact. Many plants, especially forbs, grew primarily on soil disturbed by the burrowing of prairie dogs. Prairie dog burrowing also aerated the soil and enhanced the penetration of water. The feeding and burrowing activities of smaller mammals, such as mice and voles, also had a significant impact.

However, insects were the most influential above-ground grazers in native grasslands, and roundworms had the greatest impact underground. These invertebrates accounted for more consumption of plant material than all the mammals combined. The grazers, sustained by the grassland, were instrumental in molding its character.

built up after a year or more of growth are ideal conditions for the spread of fires. Whether started by lightning or by humans, fires spread quickly through the dried mulch. The tops of plants burn to the ground, but often little damage occurs underground. Because the primary growth center of most nongrass plants is above ground and that of grasses is below ground, fire is more harmful to woody plants and nonwoody, nongrass plants (forbs).

Because grazing removes the tops of plants, it does more damage to forbs and woody plants than to grasses. Many grasses actually increase growth after light grazing. Most extensive grasslands are occupied by large grazing animals, such as the bison and pronghorn of North American grasslands. These and other grazers played important roles in the maintenance of the native grasslands and in the lives of the people who lived there.

Grassland Soils. The presence of grasslands is determined by climate, fire, and grazing, but the grasses impact their environment as well. In addition to their competitive role in excluding trees, shrubs, and forbs, grasses contribute to soil formation. All the above-ground parts of grass plants die each year, become mulch, and slowly decompose into the soil. Rainfall is generally insufficient to wash nutrients out of the reach of the grass roots, so the soil accumulates both nutrients and decaying plant material. The world's richest soils develop under these conditions.

Human Impact on Grasslands. Because of their soils, grasslands became agricultural centers. Domestic grasses became the predominant crops—corn in the tall-grass country and wheat in the mixed-grass region. The short-grass plains were too dry to support grain crops, but became an important region for grazing domestic animals.

In the process of learning what activities the grasslands could and could not support, Americans changed the grasslands of the continent forever. Farming reduced native tall-grass prairie to one of the world's rarest habitats. Although grazing had less impact on the short-grass plains, vast areas have been overgrazed severely. Grasslands in other parts of the world have been similarly abused. Given the importance of grasslands to humanity, serious conservation measures must be taken to restore their productivity.

Carl W. Hoagstrom

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The Web site of the U.S. Forest Service features information on the twenty publicly owned National Grasslands administered by the U.S. Forest Service. (www.fs.fed.us/grasslands)

Deserts

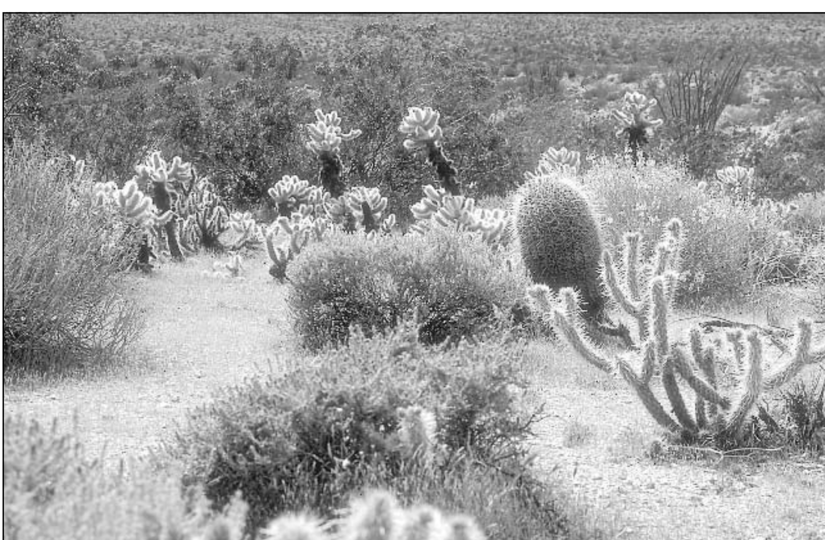
The word "desert" evokes images of searing heat and barren, windswept sand dunes. Although some deserts fit this stereotype, deserts are more than hot, dry places. Each desert is unique, but all share one important characteristic—lack of moisture. Deserts are exceptionally dry environments. The degree of their dryness is influenced by total annual rainfall, the frequency and intensity of rains, temperature, rate of evaporation, soil characteristics, and other factors.

No specific amount of rainfall serves as a criterion for deserts; however, a region is usually classified as a desert if it receives less than about 10 inches (25 centimeters) of rain per year and the rate of evaporation exceeds total annual precipitation. Each of the world's deserts is a unique environment with its own set of climatic conditions, geological characteristics, and plant and animal communities.

Most deserts experience wide shifts in daily temperature. Lack of cloud cover and low humidity allow as much as 90 percent of the Sun's heat energy striking the earth to reach the desert surface, causing daytime temperatures to climb rapidly and produce air temperatures approaching 131 degrees Fahrenheit (55 degrees Celsius) in the hottest deserts. At night, the accumulated day's heat is quickly lost to the atmosphere, and the temperature may drop to near freezing.

Types of Deserts. Deserts are found in cold as well as hot regions. Low-latitude, or subtropical, deserts occur near the latitudes of 30 degrees north and south—the Tropic of Cancer in the Northern Hemisphere and the Tropic of Capricorn in the Southern Hemisphere. The formation of low-latitude deserts is related to air circulation patterns and the physical properties of air. Warm, moist air rises at the equator, cools, and loses much of its moisture as rainfall. The cooler, drier air sinks and flows north or south toward 30 degrees north and south latitude. As the air sinks, it is compressed by the weight of the air above and warms. The resulting warm, dry air removes moisture from the land, giving rise to arid conditions and deserts. Examples of low-latitude deserts include the Sahara Desert of North Africa, the Kalahari Desert of Southern Africa, the Atacama Desert of South America, and the Victoria Desert of Australia.

Most deserts, but not all, are low-latitude regions. Rain-shadow deserts form downwind of mountain ranges. As warm, moist air is forced up and over a mountain range, it cools and loses its moisture as rain or snow. The



Typical arid desert landscape. (Digital Stock) cool, dry air descending down the opposite side of the range compresses and warms. As a result, little or no precipitation falls in the rain-shadow zone created leeward of the mountains. The lack of rainfall and low humidity within the rain-shadow zone create desert conditions. The deserts of the American southwest, leeward of the Sierra Nevada range, are rain-shadow deserts.

Some deserts form in the interiors of continents, principally because of their great distance from the ocean—the main source of moisture needed for precipitation. The Gobi Desert of Mongolia and northeastern China is an example of this kind of desert. Another kind of desert develops along warm tropical and subtropical coasts adjacent to cold ocean currents. The air above the ocean currents is cooled and contains little moisture. As this cool, dry air moves inland, it warms, causing high evaporation and producing little precipitation. Deserts of this kind include the Atacama Desert of northern Chile and southern Peru, and the Namib and Kalahari Deserts along Africa's southwest coast.

Perhaps the most unusual deserts are rarely thought of as deserts. These are the polar deserts that occur in high-latitude regions, including all of Antarctica, most of Greenland, and the northernmost parts of Alaska, Canada, and Siberia. Polar deserts are bitterly cold and dry be-

Skeleton Coast of northern Namibia in Africa. Namibia's coastal Namib Desert—after which the country is named—is an example of a desert that has develop along a warm tropical coast adjacent to a cold ocean current. The air above the ocean currents is cooled and condenses to form fog. As the air moves inland, it warms, causing high evaporation and producing little precipitation. (Corbis)

Desert vegetation adapts to arid conditions temperature extremes. Many desert plants are short-lived annuals whose life cycles are keyed to rainfall. (PhotoDisc)

cause of frigid air masses descending at the North and South Poles. Temperatures remain below freezing year-round.

Desert Lifeforms. Despite their stark appearance, deserts are second only to tropical rain forests in the variety of animals and plants living there. The Sonoran Desert of the southwestern United States and northern Mexico is home to nearly twenty-five hundred species of plants and numerous animal species, thanks in part to biannual rainy seasons. In contrast, the driest portions of Africa's Sahara Desert and South America's Atacama Desert are practically devoid of life.

Desert plants and animals are adapted to arid conditions and extremes in temperature. Many plants are short-lived annuals whose life cycles are keyed to rainfall. They survive drought conditions as seeds that quickly germinate after exposure to water. For a few short days, the desert is ablaze with color, but soon the next generation of seeds is set and the blooms wither and die. Succulents, such as cacti and agave, store water in modified roots and stems or in fleshy leaves. Woody shrubs have small leaves that reduce water loss through transpiration and develop extensive root systems to take up whatever available water is in the soil. During drought conditions, some desert shrubs shed their leaves to conserve water. Spines and thorns are a common means of defense against water-seeking animals.

Some animals avoid the heat of the day by being active at night when the desert is cooler and the humidity is higher. Others spend the day in

Wildflowers in Arizona's Grand Canyon, a desert biome. (PhotoDisc)

the shade or reside in burrows. Many desert animals are efficient at conserving and recycling water. Some obtain all of the water they need from the foods they eat. During dry periods, some animals enter a period of dormancy known as estivation. Because food and shelter are scarce, most desert mammals are small. Common animals include insects, arachnids, reptiles, and birds. Amphibians are rare as a result of the lack of permanent bodies of water.

Human beings also live in deserts. Lack of water causes many desert peoples to adopt a nomadic lifestyle. Desert soils are remarkably fertile, and irrigated crops do well if water is available. Unfortunately, human activities can negatively affect deserts and semiarid lands. The demand for water to irrigate crops or support heavily populated desert communities can severely strain limited water resources. Farming and overgrazing on semiarid lands bordering desert regions has resulted in the encroachment of deserts on productive land—a process known as desertification.

Steven D. Carey

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DesertUSA, an on-line travel and adventure guide, provides a wealth of interesting information about the deserts of the United States. Sections cover desert life, minerals and geology, and peoples and cultures. QuickTime movies show panoramic views of selected desert locations.
(www.desertusa.com)

Tundra and High Altitude Biomes

Tundra landscapes appear where long, cold winters, a permanently frozen subsoil, and strong winds combine to prevent the development of trees. The resulting landscapes tend to be vast plains with low-growing forbs and stunted shrubs. Vast areas of this biome encircle the northernmost portions of North America and Eurasia, constituting the Arctic tundra. Climatic conditions atop high mountains at all latitudes are similar; these smaller, more isolated areas are called the alpine tundra.

Permafrost. The low temperatures of the tundra cause the formation of a permanently frozen layer of soil known as permafrost. Characteristic of Arctic tundra, permafrost, which varies in depth according to latitude, thaws at the surface during the brief summers. As the permafrost below is impenetrable by both water and plant roots, it is a major factor in determining the basic nature of tundra.

The alternate freezing and thawing of soil above the permafrost creates a symmetrical patterning of the land surface characteristic of Arctic tundra. Perhaps best known are stone polygons that result when frost pushes larger rocks toward the periphery with smaller ones occupying the center of each unit. This alteration of the tundra landscape, called cryoplanation, is the major force in molding Arctic tundra landscapes.

In contrast, alpine tundra generally has little or no permafrost. Even though alpine precipitation is almost always higher than for Arctic tundra, steep grades result in a rapid runoff of water. Alpine soils are, therefore, much drier, except in the flat alpine meadows and bogs, where conditions are more like those of Arctic areas.

Vegetation. Both Arctic and alpine tundra regions are composed of plants that have adapted to the same generally stressful conditions. Biodiversity—the total number of species present—is low compared to most other ecosystems. Plant growth is slow because of the short growing seasons and the influence of permafrost. Most tundra plants are low-growing perennials that reproduce vegetatively rather than by seed. Often, they grow in the crevices of rocks that both shelter them in the winter and reflect heat onto them in summer.

Common plants of the low-lying Arctic tundra sites include various sedges, especially cottongrass, and sphagnum moss. On better-drained sites, biodiversity is higher, and various mosses, lichens, sedge, rush species, and herbs grow between dwarfed heath shrubs and willow. The arrangement of plants within a small area reflects the numerous microclimates resulting from the peculiar surface features.

Alpine plants possess many of the features of Arctic plants. However, because strong winds are such a prominent feature of the alpine environment, most of the plants grow flat on the ground, forming mats or cushions.

Below alpine tundra and south of Arctic tundra, there is the boreal or coniferous forest biome. Between the forest and tundra lies a transitional zone or ecotone. The ecotone is characterized by trees existing at their northern (or upper) limit. Especially in alpine regions, stunted, gnarled trees occupy an area called Krummholz. In North America, the Krummholz is much more prominent in the Appalachians of New England than in the western mountains.

Animal Life. Biodiversity of animals, like that of plants, is relatively low in the tundra. In Arctic regions, many animal species are circumboreal; that is, they have ranges that extend around the major continents of the north. Examples are arctic hares, reindeer, muskox, and many migratory birds such as plovers, sandpipers, and waterfowl. Few insect species occupy the Arctic tundra, but some, such as flies and mosquitoes, can be locally abundant in midsummer. Except for insects, few invertebrates can endure the harsh Arctic environment. Amphibians and reptiles are almost nonexistent.

Animals of the alpine tundra are generally more like those of adjacent lowlands than those of Arctic regions. Furthermore, they differ from mountain area to mountain area. Many bird species and some mammal species, such as sheep and elk, regularly migrate from upper mountain meadows where they spend summers to lower slopes or lowlands during winters. A few hibernate in winter, finding protection under the snow. Insects of many kinds, including grasshoppers, butterflies, beetles, and springtails, are often present.

Conservation. Like all world biomes, tundra regions are subject to degradation and destruction, especially as a result of human activities. Because of low human population density and their unsuitability for agriculture, tundras generally are less impacted by humans than are grasslands and forests. However, tundra ecosystems, when disturbed, recover slowly, if at all. As most tundra plants lack the ability to invade and colonize bare ground, the process of ecological succession that follows disturbances may take centuries. Even tire tracks left by vehicles may endure for decades. The melting of permafrost also has long-lasting effects.

The discovery of oil and gas in tundra regions, such as those of Alaska and Siberia, has greatly increased the potential for disturbances. Heavy equipment used to prospect for fossil fuels and to build roads and pipelines has caused great destruction of tundra ecosystems. As the grasses and mosses are removed, the permafrost beneath melts, resulting in soil erosion. The disposal of sewage, solid wastes, and toxic chemicals poses special problems, as such pollutants tend to persist in the tundra environment longer than in warmer areas.

Animals of the Arctic tundra, such as caribou, have been hunted by the native Inuit using traditional methods for centuries without an impact on populations. The introduction of such modern inventions as snowmobiles and rifles has caused a sharp decline in caribou numbers in some areas.

Although efforts at restoring other ecosystems, especially grasslands, have been quite successful, tundra restoration poses difficult problems. Seeding of disturbed Arctic tundra sites with native grasses is only marginally successful, even with the use of fertilizers. In alpine tundra, restoration efforts have been somewhat more successful, but involve transplanting as well as seeding and fertilizing. A recognition of natural successional patterns and long-term monitoring is a necessity in such efforts.

Thomas E. Hemmerly

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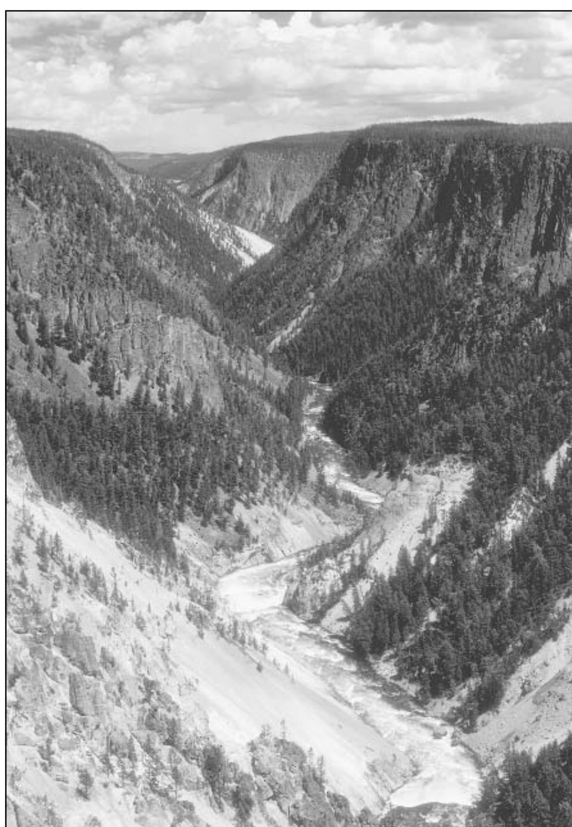
National Park Systems

The world's first national parks were established as a response to the exploitation of natural resources, disappearance of wildlife, and destruction of natural landscapes that took place during the late nineteenth century. Government efforts to preserve natural areas as parks began with the establishment of Yellowstone National Park in the United States in 1872 and were soon adopted in other countries, including Australia, Canada, and New Zealand.

While the preservation of nature continues to be an important benefit provided by national parks, worldwide increases in population and the



Creation of Yellowstone National Park in 1872 inaugurated the practice of governments providing permanent protection to unique and scenically spectacular regions. (Corbis) pressures of urban living have raised public interest in setting aside places that provide opportunities for solitude and interaction with nature.

Because national parks have been established by nations with diverse cultural values, land resources, and management philosophies, there is no single definition of what constitutes a national park. In some countries, areas used principally for recreational purposes are designated as national parks; other countries emphasize preservation of outstanding scenic, geologic, or biological resources. The terminology used for national parks also varies among countries. For example, protected areas that are similar to national parks may be called reserves, preserves, or sanctuaries.

Diverse landscapes are protected within national parks, including swamps, river deltas, dune areas, mountains, prairies, tropical rain forests, temperate forests, arid lands, and marine environments. Individual parks within nations form networks that vary with respect to size, accessibility, function, and the type of natural landscapes preserved. Some national park areas are isolated and sparsely populated, such as Greenland National Park; others, such as Peak District National Park in Great Britain, contain numerous small towns and are easily accessible to urban populations.

The functions of national parks include the preservation of scenic landscapes, geological features, wilderness, and plants and animals within their natural habitats. National parks also serve as outdoor laboratories for education and scientific research and as reservoirs for genetic information. Many are components of the United Nations International Biosphere Reserve Program.

National parks also play important roles in preserving cultures, by protecting archaeological, cultural, and historical sites. The United Nations recognizes several national parks that possess important cultural attributes as World Heritage Sites. Tourism to national parks has become important to the economies of many developing nations, especially in Eastern and Southern Africa, India, Nepal, Ecuador, and Indonesia. Parks are sources of local employment and can stimulate improvements to transportation and other types of infrastructure while encouraging productive use of lands that are of marginal agricultural use.

The International Union for Conservation of Nature has developed a system for classifying the world's protected areas, with Category II areas designated as national parks. Using this definition, there are 3,384 national parks in the world, with a mean average size of 457 square miles (1,183 sq. km.) each. Together, they cover an area of about 1.5 million square miles (4 million sq. km.), accounting for about 2.7 percent of the total land area on Earth.

North America. In 1916 management of U.S. national parks and monuments was shifted from the U.S. Army to the newly established National Park Service (NPS). The system has since grown in size to protect fifty-five

Stephen T. Mather and the U.S. National Park Service

In 1914 businessman and conservationist Stephen T. Mather wrote to Secretary of the Interior Franklin K. Lane about the poor condition of California's Yosemite and Sequoia National Parks. Lane wrote back, "if you don't like the way the national parks are being run, come on down to Washington and run them yourself." Mather accepted the challenge and became an assistant to Lane and later the first director of the U.S. National Park Service, from 1917 to 1929.

national parks, as well as other natural areas including national monuments, seashores, and preserves.

North America's second largest system of national parks is Parks Canada, created in 1930. Among the best-known Canadian parks is Banff, established in southern Alberta in 1885. Preserved within this area are glacially carved valleys, evergreen forests, and turquoise lakes. Parks Canada has the goal of protecting representative examples of each of Canada's vegetation and physiographic regions.

Mexico began providing protection for natural areas in the late nineteenth century. Among its system of forty-four national parks is Dzibilchaltún, an important Mayan archaeological site on the Yucatán Peninsula. With fewer resources available for park management, the emphasis in Mexico remains the preservation of scenic beauty for public use.

South America. Two of South America's best-known national parks are located within Argentina's park system. Nahuel Huapi National Park preserves two rare deer species of the Andes, while Iguazú National Park, located on the border with Brazil, is home to tapir, ocelot, and jaguar.

Located on a plateau of the western slope of the Andes Mountains in Chile, Lauca National Park is one of the world's highest parks, with an average elevation of more than 14,000 feet (4,267 meters)—an altitude nearly as high as the tallest mountains in the continental United States. Huascarán, another mountain park located in western Peru, boasts twenty peaks that exceed 19,000 feet (5,791 meters) in elevation. The volcanic islands of Galapagos Islands National Park, managed by Ecuador, have been of interest to biologists since British naturalist Charles Darwin studied variation and adaptation in animal species there in 1835.

Australia and New Zealand. Established in 1886, Royal was Australia's first national park. Perhaps better known to tourists, Uluru National Park in Australia's Northern Territory protects two rock domes, Ayer's Rock and Mount Olga, that rise above the plains 15 miles (40 km.) apart.

Along with Australia and other former colonies of Great Britain, New Zealand was a leader in establishing early national parks. The first of these was Tongagiro, created in 1887 to protect sacred lands of the Maori people on the North Island. New Zealand's South Island features several national parks including Fiordland, created in 1904 to preserve high mountains, forests, rivers, waterfalls, and other spectacular features of glacial origin.

Africa. Game poaching continues to be a severe problem in Africa, where animals are slaughtered for ivory, meat, and hides. Many African national parks were established to protect large game. South Africa's national park system began in 1926, when the Sabie Game Preserve of the eastern Transvaal region became Kruger National Park. Among South Africa's greatest attractions to foreign visitors, Kruger is famous for its population of lions and elephants.

East Africa is also known for outstanding game sanctuaries, such as Serengeti National Park, created prior to Tanzania's independence from Great Britain. Another national park in Tanzania, Kilimanjaro, protects Africa's highest and best-known mountain. Other African countries with well-developed park systems include Kenya, Congo-Kinshasa (formerly Zaire), and Zambia. Although there is now a network of national parks in Africa that protects a wide range of habitats in various regions, there remains a need to protect additional areas in the arid northern part of the continent that includes the Sahara Desert.

Europe. In comparison with the United States, the national park concept spread more slowly within Europe. In 1910 Germany set aside Luneburger Heide National Park near the Elbe River, and in 1913, Sweden established Sarek, Stora Sjöfallet, Peljekasje, and Abisko National Parks. Swiss National Park was founded in Switzerland in 1914, in the Lower Engadine region. Great Britain has several national parks, including Lake District, home to early nineteenth century English poet William Wordsworth. Spain's Doñana National Park, located on its southwestern coast, preserves the largest dune area on the European continent.

Asia. The system of land tenure and rural economy in many Asian countries has made it difficult for national governments to set aside large areas free from human exploitation. Many national parks established by colonial powers prior to World War II were maintained or expanded by countries following independence. For example, Kaziranga National Park is a refuge for the largest heard of rhinocerous in India. Established in 1962, Thailand's Khao Yai National Park protects a sample of the country's wildlife, while Indonesia's Komodo Island National Park preserves the habitat for the large lizards known as Komodo dragons.

In Japan, high population density has made it difficult to limit human activities within large areas. Some Japanese national parks are principally recreation areas rather than wildlife sanctuaries and may contain cultural features such as Shinto shrines. One of the best known national parks in Japan is Fuji-Hakone-Izu, which contains world-famous Mount Fuji, a volcano with a nearly symmetrical shape.

The Future. National parks serve as relatively undisturbed enclaves that protect examples of the world's most outstanding natural and cultural resources. The movement to establish these areas is a relatively recent attempt to achieve an improved balance between human activities and the earth. In recent years, rising incomes and lower costs for international travel have improved the accessibility of national parks to a larger number of persons, meaning that park visitation is likely to continue to rise.

Thomas A. Wikle

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Information on the World Wide Web

The World Conservation Monitoring Centre, an organization dedicated to providing information about conservation and sustainable use of the world's living resources, maintains a Web site with a searchable database of national parks and protected areas world wide. (www.wcmc.org.uk/data/database/un_combo.html)

Natural Resources

Soils

Soils are the loose masses of broken and chemically weathered rock mixed with organic matter that cover much of the world's land surface, except in polar regions and most deserts. The two major solid components of soil—minerals and organic matter—occupy about half the volume of a soil. Pore spaces filled with air and water account for the other half. A soil's organic material comes from the remains of dead plants and animals, its minerals from weathered fragments of bedrock. Soil is also an active, dynamic, ever-changing environment. Tiny pores in soil fill with air, water, bacteria, algae, and fungi working to alter the soil's chemistry and speed up the decay of organic material, making the soil a better living environment for larger plants and animals.

Soil Formation. The natural process of forming new soil is slow. Exactly how long it takes depends on how fast the bedrock below is weathered. This weathering process is a direct result of a region's climate and topography, because these factors influence the rate at which exposed bedrock erodes and vegetation is distributed. Global variations in these factors account for the worldwide differences in soil types.

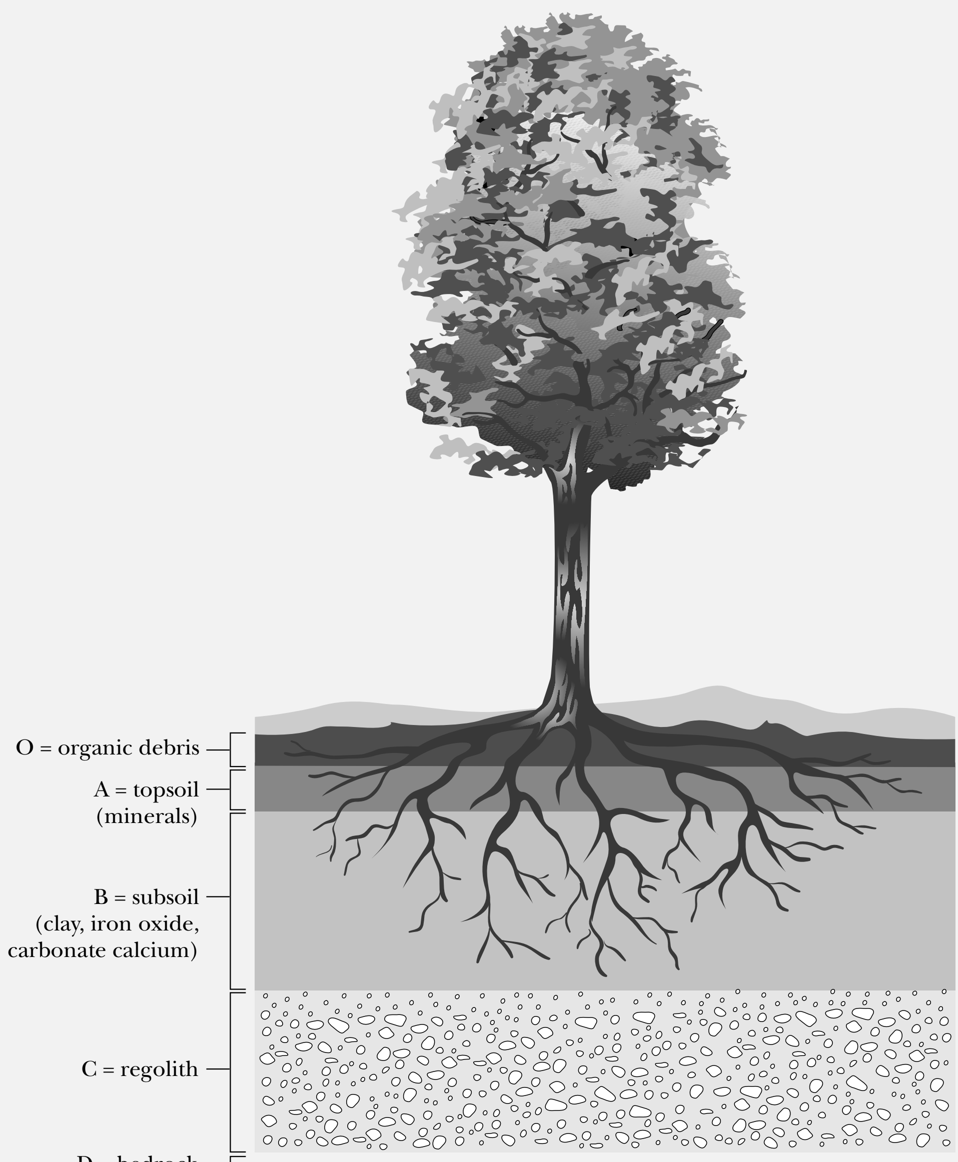
Climate is the principal factor in determining the type and rate of soil formation. Temperature and precipitation are the two main climatic factors that influence soil formation, and they vary with elevation and latitude. Water is the main agent of weathering, and the amount of water available depends on how much falls and how much runs off. The amount of precipitation and its distribution during the year influence the kind of soil formed and the rate at which it is formed. Increased precipitation usually results in increased rates of soil formation and deep soils. Temperature and precipitation also determine the kind and amount of vegetation in a region, which determines the amount of available organics.

Topography is a characteristic of the landscape involving slope angle and slope length. Topographic relief governs the amount of water that runs off or enters a soil. On flat or gently sloping land, soil tends to stay in place and may become thick, but as the slope increases so does the potential for erosion. On steep slopes, soil cover may be very thin, possibly only a few inches, because precipitation washes it downhill; on level plains, soil profiles may be several feet thick.

Types of Soil. Typically, bedrock first weathers to form regolith, a protosoil devoid of organic material. Rain, wind, snow, roots growing into cracks, freezing and thawing, uneven heating, abrasion, and shrinking and swelling break large rock particles into smaller ones. Weathered rock particles may range in size from clay to silt, sand, and gravel, with the texture and particle size depending largely on the type of bedrock. For example, shale yields finer-textured soils than sandstone. Soils formed from eroded limestone are rich in base minerals; others tend to be acidic. Generally, rates of soil formation are largely determined by the rates at which silicate minerals in the bedrock weather: the more silicates, the longer the formation time.

In regions where organic materials, such as plant and animal remains, may be deposited on top of regolith, rudimentary soils can begin to form. When waste material is excreted, or a plant or animal dies, the material usually ends up on the earth's surface. Organisms that cause decomposition, such as bacteria and fungi, begin breaking down the remains into a beneficial substance known as humus. Humus restores minerals and nutrients to the soil. It also improves the soil's structure, helping it to retain water. Over time, a skeletal soil of coarse, sandy material with trace amounts of organics gradually forms. Even in a region with good weathering rates and adequate organic material, it can take as long as fifty years to form 12 inches (30 centimeters) of soil. When new soil is formed from weathering bedrock, it can take from one hundred to one thousand years for less than an inch of soil to accumulate.

Soil Horizons

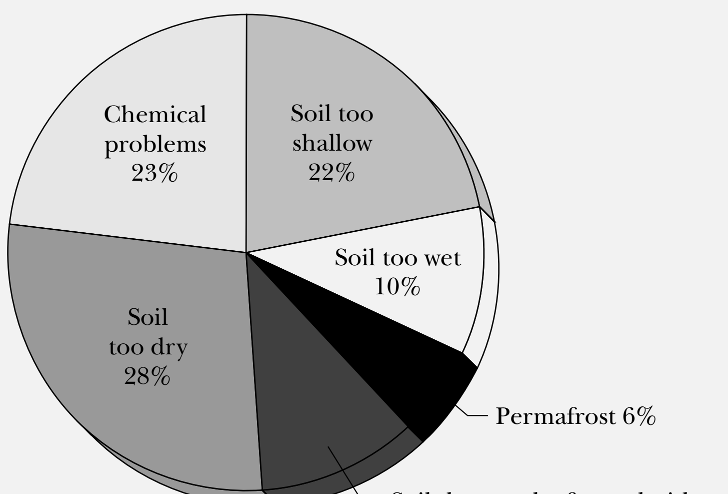


Water moves continually through most soils, transporting minerals and organics downward by a process called leaching. As these materials travel downward, they are filtered and deposited to form distinct soil horizons. Each soil horizon has its own color, texture, and mineral and humus content. The O-horizon is a thin layer of rotting organics covering the soil. The A-horizon, commonly called topsoil, is rich in humus and minerals. The B-horizon is a subsoil rich in minerals but poor in humus. The C-horizon consists of weathered bedrock; the D-horizon is the bedrock itself.

Because Earth's surface is made of many different rock types exposed at differing amounts and weathering at different rates at different locations, and because the availability of organic matter varies greatly about the planet due to climatic and seasonal conditions, soil is very diverse and fertile soil is unevenly distributed. Structure and composition are key factors in determining soil fertility. In a fertile soil, plant roots are able to penetrate easily to obtain water and dissolved nutrients. A loam is a naturally fertile soil, consisting of masses of particles from clays (less than 0.002 mm across), through silts (ten times larger) to sands (one hundred times larger), interspersed with pores, cracks, and crevices.

The Roles of Soil. In any ecosystem, soils play six key roles. First, soil serves as a medium for plant growth by mechanically supporting plant

Soil Limits to Agriculture, by Percentage of Total World Land Area



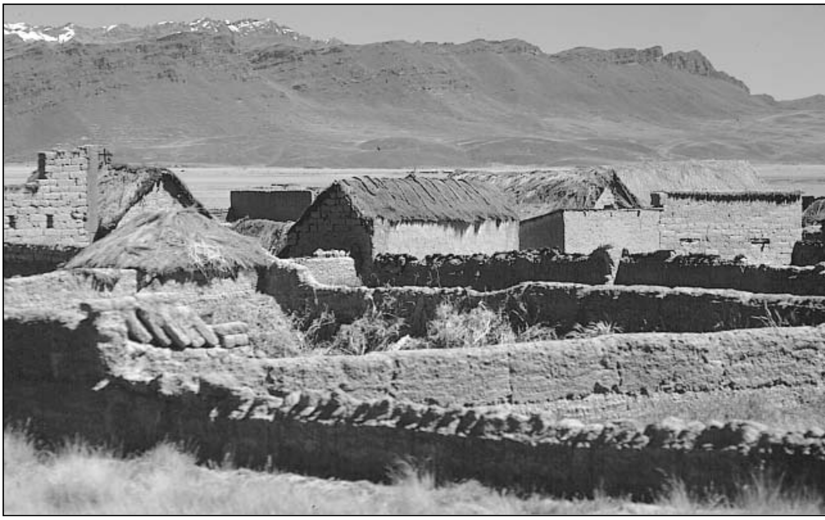
Source: United Nations Food and Agriculture Organization (FAOSTAT Database, 2000).

roots and supplying the eighteen nutrients essential for plants to survive. Different types of soil contain differing amounts of these eighteen nutrients; their combination often determines the types of vegetation present in a region, and as a result, influences the number and types of animals the vegetation can support, including humans. Humans rely on soil for crops necessary for food and fiber.

Second, the property of a particular soil is the controlling factor in how the hydrologic system in a region retains and transports water, how contaminants are stored or flushed, and at what rate water is naturally purified. Water enters the soil in the form of precipitation, irrigation, or snowmelt that falls or runs off soil. When it reaches the soil, it will either be surface water, which evaporates or runs into streams, or subsurface water, which soaks into the soil where it is either taken up by plant roots or percolates downward to enter the groundwater system. Passing through soil, organic and inorganic pollutants are filtered out, producing pure groundwater.

Soil also functions as an air-storage facility. Air is pushed into and drawn out of the soil by changes in barometric pressure, high winds, percolating water, and diffusion. Pore spaces within soil provide access to oxygen to organisms living underground as well as to plant roots. Soil

For thousands of years the people of the American Southwest have used the red clay soil to make adobe bricks—a building material with excellent insulating properties that is ideal for the region. (PhotoDisc)



Buildings and walls made almost entirely from mud bricks in the South American Andes. (Clyde L. Rasmussen)

pore spaces also contain carbon dioxide, which many bacteria use as a source of carbon.

Soil is nature's recycling system, through which organic waste products and decaying plants and animals are assimilated and their elements made available for reuse. The production and assimilation of humus within soil converts mineral nutrients into forms that can be used by plants and animals, who return carbon to the atmosphere as carbon dioxide. While dead organic matter amounts to only about 1 percent of the soil by weight, it is a vital component as a source of minerals.

Soil provides a habitat for many living things, from insects to burrowing animals, from single microscopic organisms to massive colonies of subterranean fungi. Soils contain much of the earth's genetic diversity, and a handful of soil may contain billions of organisms, belonging to thousands of species. Although living organisms only account for about 0.1 percent of soil by weight, 2.5 acres (one hectare) of good-quality soil can contain at least 300 million small invertebrates—mites, millipedes, insects, and worms. Just 1 ounce (30 grams) of fertile soil can contain one million bacteria of a single type, one hundred million yeast cells, and fifty thousand fungus mycelium. Without these, soil could not convert nitrogen, phosphorus, and sulphur to forms available to plants.

Finally, soil is an important factor in human culture and civilization. Soil is a building material used to make bricks, adobe, plaster, and pottery, and often provides the foundation for roads and buildings. Most important, soil resources are the basis for agriculture, providing people with their dietary needs.

Toxic waste dump. (PhotoDisc)

Because the human use of soils has been haphazard and unchecked for millennia, soil resources in many parts of the world have been harmed severely. Human activities, such as overcultivation, inexpert irrigation, overgrazing of livestock, elimination of tree cover, and cultivating steep slopes, have caused natural erosion rates to increase many times over. As a result of mismanaged farm and forest lands, escalated erosional processes wash off or blow away an estimated seventy-five billion tons of soil annually, eroding away one of civilization's crucial resources.

Randall L. Milstein

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Water

Life on earth requires water—without it, life on earth would cease. As human populations grow, the freshwater resources of the world become scarcer and more polluted, while the need for clean water increases. Although nearly three-quarters of the earth's surface is covered with water, only about 0.3 percent of that water is freshwater suitable for consumption and irrigation. This is because more than 97 percent of the earth's water is ocean salt water, and most of the remaining freshwater is frozen in the Antarctic ice cap. Only the small amounts that remain in lakes, rivers, and groundwater is available for human use.

All of earth's water cycles between the ocean, land, atmosphere, plants, and animals over and over. On average, a molecule of surface water cycles from the ocean, to the atmosphere, to the land and back again in less than two weeks. Water consumed by plants or animals takes longer to return to the oceans, but eventually the cycle is completed.

Water's Uses. Water supports all living creatures. People use it not only for drinking, cooking, and bathing, but also travel on it, make electricity with it, fish in it, irrigate crops with it, and use it for recreation. Globally, more than 3,240 million acre-feet of water is used, most of it for agriculture. Of the freshwater used, agriculture accounts for 69 percent, industry uses 23 percent, and domestic and municipal activities use 9 percent. Among agricultural uses, it takes 11 gallons of water to grow 1 serving of broccoli, 56 gallons to produce a serving of cheese, and 2,510 gallons for a pound of beef. In industry, 151 gallons of water are needed to make one Sunday newspaper and 65,257 gallons are used in the manufacture of the average car.

An average Westerner living in an urban setting uses approximately 159 gallons per day for personal and domestic uses, such as washing, cooking, and watering the lawn. As the world's population grows, the demand for freshwater will also increase. A study by the World Bank concluded that approximately 80 percent of human illness results from insufficient water supplies and poor water quality caused by lack of sanitation, so careful management of water resources is essential for improving the health of people in the twenty-first century.

Groundwater Supply and Quality. The amount of groundwater in the earth is seventy times greater than all of the freshwater lakes combined. Groundwater is held within the rocks below the ground surface and is the primary source of water in many parts of the world. In the United States, approximately 50 percent of the population uses some groundwater. However, problems with both supplies and quality threaten future use of groundwater.

The U.S. Environmental Protection Agency (EPA) found that 45 percent of the large public water systems in the United States that use groundwater were contaminated with synthetic organic chemicals that posed potential health threats. Another major problem occurs when groundwater is used faster than it is replaced by precipitation infiltrating through the ground surface. Many of the arid regions of earth are already suffering from this problem. For example, one-third of the wells in Beijing, China, have gone dry due to overuse. In the United States, the Ogallala Aquifer of the Great Plains, the largest in North America, is being severely overused. This aquifer irrigates 20 percent of U.S. farmland, and one-fourth of this groundwater resource is expected to be gone by 2020.

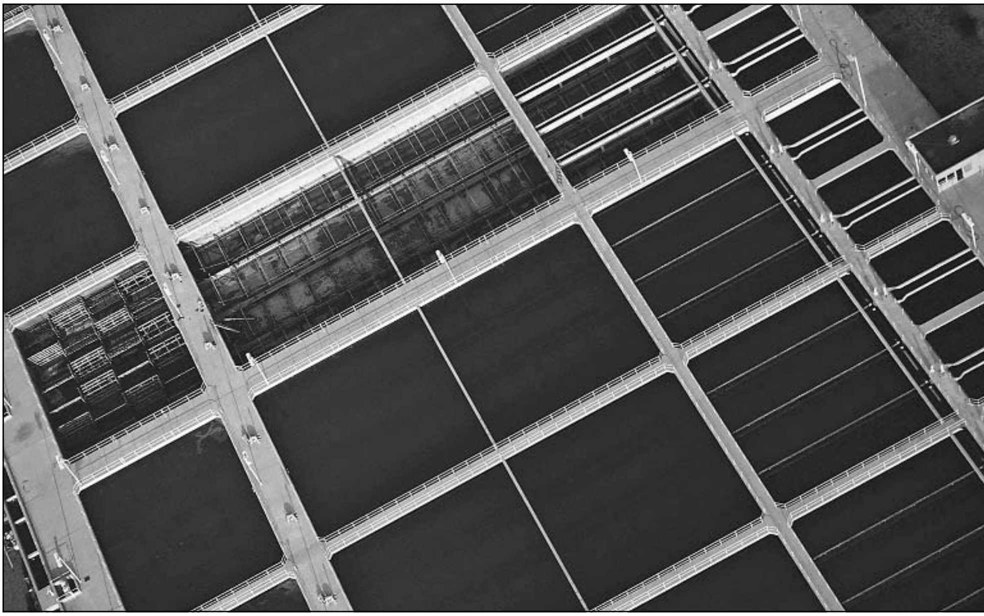
Surface Water Supply and Quality. Surface water is used for transportation, recreation, electrical generation, and consumption. Ships use rivers and lakes as transport routes, people fish and boat on rivers and lakes, and dams on rivers often are used to generate electricity. The largest river on earth is the Amazon in South America, which has an average flow of 212,500 cubic meters per second, more than twelve times greater than North America's Mississippi River. Earth's largest lake—Lake Baikal in Russia—has a volume of approximately 5,280 cubic miles (22,000 cubic km.), equal to the volume of all five of North America's Great Lakes combined.

Although surface water has more uses, it is more prone to pollution than groundwater. Almost every human activity affects surface water quality. For example, water is used to create paper for books, and some of the chemicals used in the paper process are discharged into surface water sources. Most foods are grown with agricultural chemicals, which can contaminate water sources. In 1994 the EPA reported that approximately 44 percent of U.S. lakes and 37 percent of U.S. rivers are unsafe for fishing and swimming.

Earth's Future Water Supply. Inadequate water supplies and water quality problems threaten the lives of more than one billion people worldwide. The World Health Organization estimates that polluted water causes the death of fifteen million children under five years of age each

The World and North America's Greatest Rivers and Lakes

	World	*North America*
Longest river	Nile (North Africa) 4,130 miles (6,600 km.)	Missouri-Mississippi (United States) 3,740 miles (6,000 km.)
Largest river by average discharge	Amazon (South America) 6,181,000 cubic feet/second (175,000 cubic meters/second)	Missouri-Mississippi (United States) 600,440 cubic feet/second (17,000 cubic meters/second)
Largest freshwater lake by volume	Lake Baikal (Russia) 5,280 cubic miles (22,000 cubic km.)	Lake Superior 3,000 cubic miles (12,500 cubic km.)



The water consumed in most urban centers passes through treatment plants that remove impurities and chemically treat the water to kill potentially harmful organisms. (PhotoDisc)

year and affects the health of 20 percent of the earth's population. As the world's population grows, these problems are likely to worsen.

The United Nations estimates that if current consumption patterns continue, two-thirds of the world's people will live in water-stressed conditions by 2025. Since access to clean freshwater is essential to health and a decent standard of living, efforts must be made to clean up and conserve the planet's freshwater, or billions of people in the twenty-first century will be negatively affected.

Mark M. Van Steeter

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Renewable Resources

Most renewable resources are living resources, such as plants, animals, and their products. With careful management, human societies can harvest such resources for their own use without imperiling future supplies. However, many historical instances of resource mismanagement have led to the virtual destruction of valuable resources.

Forests. Forests are large tracts of land supporting growths of trees and perhaps some underbrush or shrubs. Trees constitute probably the earth's most valuable, versatile, and easily grown renewable resource. When they are harvested intelligently, their natural environments continue to replace them. However, if a harvest is beyond the environment's ability to restore the resource that had been present, new and different plants and animals will take over the area. This phenomenon has been demonstrated many times in overused forests and grasslands that reverted to scrubby brushlands. In the worst cases, the abused lands degenerated into barren deserts.

The forest resources of the earth range from the tropical rain forests with their huge trees and broad diversity of species to the dry savannas featuring scattered trees separated by broad grasslands. Cold, subarctic lands support dense growths of spruces and firs, while moderate temperature regimes produce a variety of pines and hardwoods such as oak and ash. The forests of the world cover about 29 percent of the land surface, as compared with the oceans, which cover about 71 percent of the global surface.

Harvested wood, cut in the forest and hauled away to be processed, is termed roundwood. Globally, the cut of roundwood for all uses amounts to about 122.2 billion cubic feet (3.5 billion cubic meters). Slightly more than half of the harvested wood is used for fuel, including charcoal.

Roundwood that is not used for fuel is described as industrial wood and used to produce lumber, veneer for fine furniture, and pulp for paper products. Some industrial wood is chipped to produce such products as subflooring and sheathing board for home and other building construction. Most roundwood harvested in Africa, South America, and Asia is used for fuel. In contrast, roundwood harvested in North America, Europe, and the former Soviet Union generally is produced for industrial use.

It is easy to consider forests only in the sense of the useful wood they produce. However, many forests also yield valuable resources such as rubber, edible nuts, and what the U.S. Forest Service calls special forest products. These include ferns, mosses, and lichens for the florist trade, wild edible mushrooms such as morels and matsutakes for domestic markets and for export, and mistletoe and pine cones for Christmas decorations.

There is growing interest among the industrialized nations of the world in a unique group of forest products for use in the treatment of human disease. Most of them grow in the tropical rain forests. These medicinal plants have long been known and used by shamans (traditional medicine men). Hundreds of pharmaceutical drugs, first used by shamans, have been derived from plants, many gathered in tropical rain forests. The drugs include quinine, from the bark of the cinchona tree, long used to combat malaria, and the alkaloid drug reserpine. Reserpine, derived from the roots of a group of tropical trees and shrubs, is used to treat high blood pressure (hypertension) and as a mild tranquilizer. It has been estimated that 25 percent of all prescriptions dispensed in the United States contain ingredients derived from tropical rain forest plants. The value of the finished pharmaceuticals is estimated at $6.25 billion per year.

Scientists screening tropical rain forest plants for additional useful medical compounds have drawn on the knowledge and experience of the shamans. In this way, the scientists seek to reduce the search time and costs involved in screening potentially useful plants. Researchers hope that somewhere in the dense tropical foliage are plant products that could treat, or perhaps cure, diseases such as cancer or AIDS.

Many as-yet-undiscovered medicinal plants may be lost forever as a consequence of deforestation of large tracts of equatorial land. The trees are cut down or burned in place and the forest converted to grassland for raising cattle. The tropical soils cannot support grasses without the input of large amounts of fertilizer. The destruction of the forests also causes flooding, leaving standing pools of water and breeding areas for mosquitoes, which can spread malaria and yellow fever.

Marine Resources. When renewable marine resources such as fish and shellfish are harvested or used, they continue to reproduce in their envi-

Indiscriminate use of huge fishing nets threatens the survival of other animal species, including dolphins. (PhotoDisc)

ronment, as happens in forests and with other living natural resources. However, like overharvested forests, if the marine resource is overfished—that is, harvested beyond its ability to reproduce—new, perhaps undesirable, kinds of marine organisms will occupy the area. This has happened to a number of marine fishes, particularly the Atlantic cod.

When the first Europeans reached the shores of what is now New England in the early seventeenth century, they encountered vast schools of cod in the local ocean waters. The cod were so plentiful they could be caught in baskets lowered into the water from a boat.

At the height of the New England cod fishery, in the 1970's, efficient, motor-driven trawlers were able to catch about 32,000 tons. The catch began to decline mostly as a result of the impact of fifteen different nations fishing on the cod stocks. As a result of overfishing, rough species such as dogfish and skates constitute 70 percent of the fish in the local waters. Experts on fisheries management decided that fishing for cod had to be stopped.

The decline of the cod was attributed to two causes: a worldwide demand for more fish as food and great changes in the technology of fishing. The technique of fishing progressed from a lone fisher with a baited hook and line, to small steam-powered boats towing large nets, to huge diesel-powered trawlers towing monster nets that could cover a football field. Some of the largest trawlers were floating factories. The cod could be skinned, the edible parts cut and quick-frozen for market ashore, and the skin, scales, and bones cooked and ground for animal feed and oil. A lone fisher was lucky to be able to catch 1,000 pounds (455 kilograms) in one day. In contrast, the largest trawlers were capable of catching and processing 200 tons per day.

The world ocean population of swordfish has also declined dramatically. With a worldwide distribution, these large members of the billfish family have been eagerly sought after as a food fish. Because swordfish have a habit of basking at the surface, fishermen learned to sneak up on the swordfish and harpoon them. Advances in technology led to the doom of the swordfish. Fishermen began to catch swordfish with fishing lines 25 to 40 miles (40 to 65 kilometers) long. Baited hooks hung at intervals on the main line successfully caught many swordfish, as well as tuna and large sharks. Whereas the harpoon fisher took only the largest (thus most valuable) swordfish, the longline gear was indiscriminate, catching and killing many swordfish too small for the market, as well as sea turtles and dolphins

As a result of the catching and killing of both sexually mature and immature swordfish, the reproductive capacity of the species was greatly reduced. Harpoons killed mostly the large, mature adults that had spawned several times. Longlines took all sizes of swordfish, including the small ones that had not yet reached sexual maturity and spawned. The decline of the swordfish population was quickly obvious in the reduced landings. In one seven-year period, swordfish landings off the east coast of the United States dropped by almost 60 percent. At the same time, the number of longline hooks set in the same area increased by 70 percent.

As a gesture of support for restoring swordfish stocks in the world's oceans, many restaurants in the United States voluntarily removed swordfish from their menus. It is hoped this action will encourage the United States government, and perhaps other nations, to develop an effective recovery plan for the swordfish.

Albert C. Jensen

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Nonrenewable Resources

Nonrenewable resources are useful raw materials that exist in fixed quantities in nature and cannot be replaced. They differ from renewable resources, such as trees and fish, which can be replaced if managed correctly. Most nonrenewable resources are minerals—inorganic and organic substances that exhibit consistent chemical composition and properties. Minerals are found naturally in the earth's crust or dissolved in seawater. Of roughly two thousand different minerals, about one hundred are sources of raw materials that are needed for human activities. Where useful minerals are found in sufficiently high concentrations—that is, as ores—they can be mined as profitable commercial products.

Economic nonrenewable resources can be divided into four general categories: metallic (hardrock) minerals, which are the source of metals such as iron, gold, and copper; fuel minerals, which include petroleum (oil), natural gas, coal, and uranium; industrial (soft rock) minerals, which provide materials like sulfur, talc, and potassium; and construction materials, such as sand and gravel.

Gold in its native state. (U.S. Geological Survey)

Nonrenewable resources are required as direct or indirect parts of all the products that humans use. For example, metals are necessary in industrial sectors such as construction, transportation equipment, electrical equipment and electronics, and durable goods—long-lasting products such as refrigerators and stoves. Fuel minerals provide energy for transportation, heating, and electrical power. Industrial minerals provide ingredients needed in products ranging from baby powder to fertilizer to the space shuttle. Construction materials are used in roads and buildings.

Location. When minerals have naturally combined together (aggregated) they are called rocks. The three general rock categories are igneous, sedimentary, and metamorphic. Igneous rocks are created by the cooling of molten material (magma). Sedimentary rocks are caused when weathering, erosion, transportation, and compaction or cementation act on existing rocks.

Metamorphic rocks are created when the other two types of rock are changed by heat and pressure. The availability of nonrenewable resources from these rocks varies greatly, because it depends not only on the natural distribution of the rocks but also on people's ability to discover and process them. It is difficult to find rock formations that are covered by the ocean, material left by glaciers, or a rain forest. As a result, nonrenewable resources are distributed unevenly throughout the world.

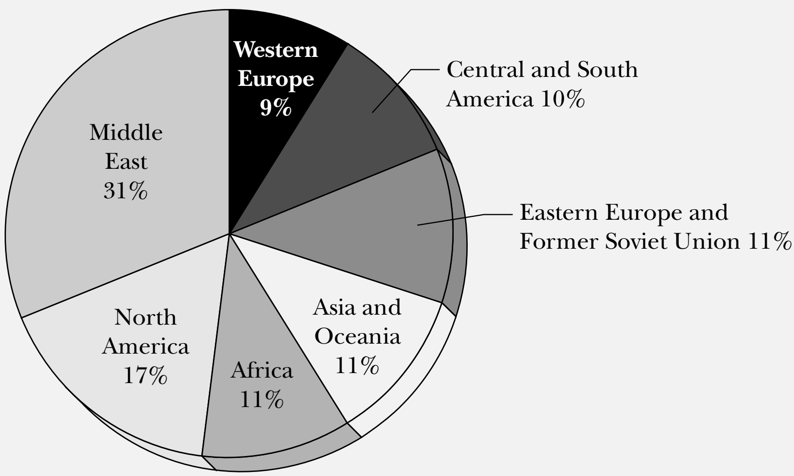
Some nonrenewable resources, such as construction materials, are found easily around the world and are available almost everywhere. Other nonrenewable resources can only be exploited profitably when the useful minerals have an unusually high concentration compared with their average concentration in the earth's crust. These high concentrations are caused by rare geological events and are difficult to find. For example, an exceptionally rare nonrenewable resource like platinum is produced in only a few limited areas.

No one country or region is self-sufficient in providing all the nonrenewable resources it needs, but some regions have many more nonrenewable resources than others. Minerals can be found in all types of rocks, but some types of rocks are more likely to have economic concentrations than others. Metallic minerals often are associated with shields (blocks) of old igneous (Precambrian) rocks. Important shield areas near the earth's surface are found in Canada, Siberia, Scandinavia, and Eastern Europe. Another important shield was split by the movement of the continents, and pieces of it can be found in Brazil, Africa, and Australia.

Similar rock types are in the mountain formations in Western Europe, Central Asia, the Pacific coast of the Americas, and Southeast Asia. Minerals for construction and industry are found in all three types of rocks and are widely and randomly distributed among the regions of the world.

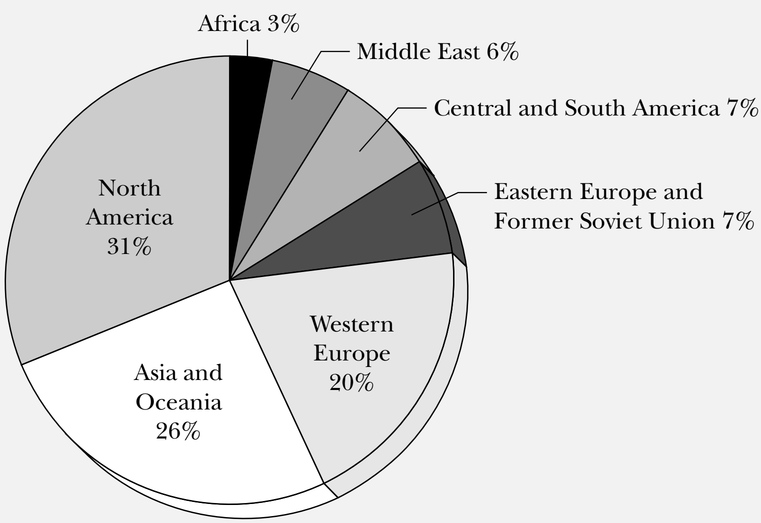
The fuel minerals—petroleum and natural gas—are unique in that they occur in liquid and gaseous states in the rocks. These resources must be captured and collected within a rock site. Such a site needs source

Production of World Petroleum by Region, 1998



Source: International Energy Annual, Energy Information Administration, U.S. Department of Energy, 1998.

Consumption of World Petroleum by Region, 1998



Source: International Energy Annual, Energy Information Administration, U.S. Department of Energy, 1998.

rock to provide the resource, a rock type that allows the resource to collect, and another surrounding rock type that traps the resource. Sedimentary rock basins are particularly good sites for fuel collection. Important fuel-producing regions are the Middle East, the Americas, and Asia.

Impact on Human Settlement. Nonrenewable resources have always provided raw materials for human economic development, from the flint used in early stone tools to the silicon used in the sophisticated chips in personal computers. Whole eras of human history and development have been linked with the nonrenewable resources that were key to the period and its events. For example, early human culture eras were called the Stone, Bronze, and Iron Ages.

Political conflicts and wars have occurred over who owns and controls nonrenewable resources and their trade. One recent example is the Persian Gulf War of 1991. Many nations, including the United States, fought against Iraq over control of petroleum production and reserves in the Middle East.

Since the actual production sites often are not attractive places for human settlement and the output is transportable, these sites are seldom important population centers. There are some exceptions, such as Johannesburg, South Africa, which grew up almost solely because of the gold found there. However, because it is necessary to protect and work the production sites, towns always spring up near the sites. Examples of such towns can be found near the quarries used to provide the material for the great monuments of ancient Egypt and in the Rocky Mountains of North America near gold and silver mines. These towns existed because of the nonrenewable resources nearby and the needs of the people exploiting them; once the resource was gone, the towns often were abandoned, creating "ghost towns," or had to find new purposes, such as tourism.

More important to human settlement is the control of the trade routes for nonrenewable resources. Such controlling sites often became regions of great wealth and political power as the residents taxed the products

One of the most famous ghost towns from California's pioneer gold mining days is Bodie, in the eastern Sierra Nevadas. (Corbis) that passed through their community and provided the necessary services and protection for the traveling traders. Just one example of this type of development is the great cities of wealth and culture that arose along the trade routes of the Sahara Desert and West Africa like Timbuktu (in present-day Mali) and Kumasi (in present-day Ghana) based on the trade of resources like gold and salt.

Even with modern transportation systems, ownership of nonrenewable resources and control of their trade is still an important factor in generating national wealth and economic development. Modern examples include Saudi Arabia's oil resources, Egypt's control of the Suez Canal, South Africa's gold, Chile's copper, Turkey's control over the Bosporus Strait, and Indonesia's metals and oil.

Gary A. Campbell

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A good general source of information on nonrenewable resources is the U.S. Geological Survey's (USGS) Web site for Commodity Statistics and Information, which provides articles on the worldwide supply, demand, and use of minerals and other materials. (minerals.usgs.gov/minerals/pubs/commodity/)

Human Geography

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Human Society and the Earth

The Human Environment

No person lives in a vacuum. Every human being and community is surrounded by a world of external influences with which it interacts and by which it is affected. In turn, humans influence and change their environments: sometimes intentionally, sometimes not, and sometimes with effects that are harmful to these environments, and, in turn, to humans themselves. As the only tool-creating animal, humans have always shaped the world in which they live, but developments over the past few centuries have greatly enhanced this capacity.

During the last decades of the twentieth century, people became alarmed over the effects of modern technology and accelerating human population growth in the world. Travel and transportation among the world's regions have been made surer, safer, and faster, and global communication is virtually instantaneous. The human environment is no longer a matter of local physical, biological, or social conditions, or even of merely national or regional concerns—the postmodern world has become a true global community.

Students of human geography divide the human environment into three broad areas: the physical, biological, and social environments. The study of ecology describes and analyzes the interactions of biological forms (mainly plants and animals) and seeks to uncover the optimal means of species cooperation, or symbiosis. Everything that humans do affects life and the physical world around them, and this world provides potentials for and constraints on how humans can live.

As people gained and communicated ever-greater knowledge about the world, their abilities to alter and shape it increased. Even ten thousand years ago, people cut down trees, scratched the earth's surface with simple plows, and replaced diverse plant forms with single crops. From this basic agricultural technology grew more complex human communities, and people were freed from the need to hunt and gather. The alteration of the local ecosystems could have deleterious effects, however, as gardens turned eventually to deserts in places like North Africa and what later became Iraq. Those who kept herds of animals grazed them in areas rich in grasses, and animal fertilizer helped keep them rich. Still, the herders moved on when their animals overgrazed, leaving erosion and even desertification in their wake. Modern people have a far greater ability to alter their environments than did Neolithic people, and ecologists are concerned about the negative effects of modern alterations.

The Environmental Debate

Scientists, politicians, and businessmen have long debated the nature, extent, and future of environmental degradation. Most alarming was the 1972 report by the Club of Rome entitled *Limits to Growth.* Computer projections of population growth and the overuse of natural resources painted a bleak picture of overcrowding and ecological disaster. Two decades later, the group published *Beyond the Limits,* which modified the earlier projections but retained its pessimism in the absence of major changes in human behavior. U.S. vice president Al Gore, in his book *Earth in the Balance* (1992), also painted a grim picture, which he believed could be averted only by large-scale changes in the industrialized world's consumption habits.

Optimists, led by economists and social scientists and bolstered by scientific advances and forecasting, refuted or minimized the dire warnings of pessimistic ecologists. Their works emphasize the resilience of the natural and biological environments rather than their susceptibility to human interference. Julian L. Simon and Herman Kahn's book *The Resourceful Earth* (1984) emphasizes human progress in alleviating pollution, increasing food supplies, and reducing birthrates worldwide.

The Physical Environment. The earth's biosphere is made up of the atmosphere—the mass of air surrounding the earth; the hydrosphere—bodies of water; and the lithosphere—the outer portion of the earth's crust. Each of these, alone and working together, affects human life and human communities.

Climate and weather at their most extreme can make human habitation impossible, or at least extremely uncomfortable. Desert and polar climates do not have the liquid water, vegetation, and animal life necessary to sustain human existence. Elsewhere, people must adjust to even mild variations in temperature and precipitation, and do so with clothing and shelter. Excess rain can be drained off, and arid areas irrigated. Heating and, more recently, air conditioning can create healthy microclimates, whatever the external conditions. Most people live in temperate zones where weather extremes are rare or dealt with by technological adaptation. Food can be grown locally, and transportation is effective throughout the year. Local droughts, tornadoes, hurricanes, heavy winds, lightning, and hail can have devastating effects even in the most comfortable of climates.

The hydrosphere affects the atmosphere in countless ways, and provides the water so necessary for human and other life. Bodies of water provide plants and animals for food, transportation routes, and aesthetic pleasure to people, and often serve to flush away waste products. People locate near water sources for all of these reasons, but sometimes suffer from sudden shifts in the water level, as in tidal waves (tsunamis) or flooding. Encroachment of salt water into freshwater bodies (salination) is a problem that can have natural or human causes.

The lithosphere provides the solid, generally dry surface on which people usually live. It has been shaped by the atmosphere (especially wind and rain that erode rocks into soil) and the hydrosphere (for example, alluvial deposits and beach erosion). It serves as the base for much plant life and for most agriculture. People have tapped its mineral deposits and reshaped it in many places; it also reshapes itself through, for example, earthquakes and volcanic eruption. Its great variations, including vegetation, draw or repel people, who exploit or enjoy them for reasons as varied as recreation, military defense, or farming.

The Biological Environment. Humans share the earth with something between five and thirty million different species of plants, animals, and microorganisms—about about two million of which have been identified and named. As part of the natural food chain, people rely upon other life forms for nourishment. Through perhaps the first 99 percent of human history, people harvested the bounty of nature in its native setting, by hunting and gathering.

Domestication of plants and animals, beginning about ten thousand years ago, provided humans a more stable and reliable food supply, revolutionizing human communities. Being omnivores, people can use a wide variety of plants and animals for food, and they have come to control or manage most important food sources through herding, agriculture, or mechanized harvesting. Which plants and animals are chosen as food, and thus which are cultivated, bred, or exploited, are matters of human culture, not, at least in the modern world, of necessity.

Huge increases in human population worldwide have, however, put tremendous strains on provision of adequate nourishment. Areas poorly endowed with foodstuffs or that suffer disastrous droughts or blights may benefit from the importation of food in the short run, but cannot sustain high populations fostered by medical advances and cultural considerations.

Human beings themselves are also hosts to myriad organisms, such as fungi, viruses, bacteria, mites, worms, and lice. While people usually can coexist with these, at times they are destructive and even fatal to the human organism. Public health and medical efforts have eradicated some of humankind's biological enemies, but others remain and baffle modern science.

The presence of these enemies to health once played a major role in locating human habitations to avoid so-called "bad air" (*mal-aria*) and the breeding grounds of tsetse flies or other pests. The use of pesticides and draining of marshy grounds have alleviated a good deal of human suffering. Human efforts can also control or eliminate biological threats to the plants and animals used for food, clothing, and other purposes.

Social Environments. Human reproduction and the nurturing of young require cooperation among people. Over time, people gathered in groups that were diverse in age if not in other qualities, and the development of towns and cities eventually created an environment in which otherwise unrelated people interacted on intimate and constructive levels. Specialization, or division of labor, created a higher level of material wealth and culture and ensured interpersonal reliance.

The pooling of labor—both voluntary and forced—allowed for the creation of artificial living environments that defied the elements and met human needs for sustenance. Some seemingly basic human drives of exclusivity and territoriality may be responsible for interpersonal friction, violence and, at the extreme, war. Physical differences, such as size, skin, or hair color, and cultural differences, including language, religion, and customs, have often divided humans or communities. Even within close quarters such as cities, people often separate themselves along lines of perceived differences. Human social identity comes from shared characteristics, but which things are seen as shared, and which as differentiating, is arbitrary.

People can affect their social environment for good and ill through trade and war, cooperation and bigotry, altruism and greed. While people still are somewhat at the mercy of the biological and physical environments, technological developments have balanced the human relationship with these. Negative effects of human interaction, however, often offset the positive gains. People can seed clouds for rain, but also pollute the atmosphere around large cities, create acid rain, and perhaps contribute to global warming and depletion of the ozone layer around the earth.

Human actions can direct water to where it is needed, but people also drain freshwater bodies and increase salination, pollute streams, lakes, and oceans, and encourage flooding by modifying river beds. People have terraced mountainsides and irrigated them to create gardens in mountains and deserts, but also lose about 75 billion metric tons of soil to erosion and 15 million acres (6 million hectares) of grazing land to desertification each year. These negative effects not only jeopardize other species of terrestrial life, but also humans' ability to live comfortably, or perhaps at all.

Globalization. Humankind's ability to affect its natural environments has increased enormously in the wake of the Industrial Revolution. The harnessing of steam, chemical, electrical, and atomic energy has enabled people to transform life on a global scale. Economically, the Western world has come to dominate global markets, and computer and satellite technology have made even remote parts of the globe reliant on Western information and products. Efficient transportation of goods and people over huge distances has eliminated physical barriers to travel and commerce. The power and influence of multinational corporations, and of national corporations in international markets, has become great. With the Internet, a mastery of basic English is almost essential, and global news networks based in the United States further connect the peoples of the earth.

Human environmental problems also have a global scope: Ozone de-

In many mountainous parts of the world, people try to maximize the output of their land by terracing slopes to utilize every possible fragment of space. (PhotoDisc)

pletion, changes in ocean temperatures, global warming, and the spread of disease by travelers have become planetary concerns. International agencies seek to deal with such matters, and also social and political concerns once left to nations or colonial powers, such as population growth, the provision of justice, or environmental destruction within a country. Pessimists warn of horrendous trends in population and ecological damage, and further deterioration of human life and its environments. Optimists dismiss negative reports as exaggerated and alarmist, or expect further technological advances to mitigate the negative effects of human action.

Joseph P. Byrne

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Population Growth and Distribution

On October 13, 1999 the United Nations (U.N.) officially announced that the total population of the earth had reached 6 billion people. Both that number and that date were estimates, as no one could be sure exactly how many were alive on the earth that day. Indeed, the U.S. Census Bureau estimated that the world's population reached the figure of 6 billion four months earlier than the date of the U.N. estimate.

The population of the world has been growing steadily for thousands of years and has grown more in some places than in others. The population of the United States on October 13, 1999 was approximately 270 million. That meant that about 1 in 22 people on the planet lived in the United States. The populations of Canada, California, and the metropolitan area of Mexico City were each about 30 million people on that day, meaning that 1 in 200 people on the earth lived in Canada, 1 in 200 lived in California, and 1 in 200 lived in Mexico City. However, Canada is a much larger area than California, and California is much larger than Mexico City.

India's population on October 13, 1999, was just about 1 billion—1 in 6 people on the planet. China's population was about 1.25 billion—about 1 in 5 people on the planet. Although China was the most populous nation in the world in 1999, it was expected that in the twenty-first century India's population would surpass that of China.

How Populations Are Counted. The U.S. Constitution requires that a census, or enumeration, of the population of the United States be conducted every ten years. The U.S. Census Bureau mails out millions of census forms and pays thousands of people (enumerators) to count people that did not fill out their census forms. This task cost about 4.5 billion dollars in the year 2000. Despite this great effort, millions of people are probably not counted in every U.S. census. Moreover, many countries have much less money to spend on censuses and more people to count. Therefore, information about the population of many poor or less-developed countries is even less accurate than that for the population of the United States. It is for these reasons that it is impossible to say that the population of the world reached exactly 6 billion people on exactly October 13, 1999.

Counting how many people were alive a hundred, a thousand, or hundreds of thousands of years ago is even more difficult. Estimates are made from archaeological findings, which include human skeletons, ruins of ancient buildings, and evidence of ancient agricultural practices. Historical records of births, deaths, taxes paid, and other information are also used. Although it is not possible to estimate the global population one thousand years ago with great accuracey, it is a fascinating topic, and many people have participated in estimating the total population of the planet through the ages.

History of Human Population Growth. Ancient ancestors of humans, known as hominids, were alive in Africa and Europe around one million years ago. It is believed that modern humans *(homo sapiens sapiens)* coexisted with the Neanderthals (*homo sapiens neandertalensis*) about 100,000 years ago. By 8000 B.C.E. (10,000 years ago) fully modern humans numbered around 8 million. If the presence of archaic *homo sapiens* is accepted as the beginning of the human population one million years ago, then the first 990,000 years of human existence are characterized by a very low population growth rate (15 persons per million per year).

Around 10,000 years ago, humans began a practice that dramatically changed their growth rate: planting food crops. This shift in human history, called the Agricultural Revolution, paved the way for the development of cities, government, and civilizations. Before the Agricultural Revolution, there were no governments to count people. The earliest censuses were conducted less than 10,000 years ago in the ancient civilizations of Egypt, Babylon, China, Palestine, and Rome. For this reason, historical estimates of the earth's total population are difficult to make. However, there is no argument that human numbers have increased dramatically in the past 10,000 years. The dramatic changes in the growth rates of the human population are typically attributed to three significant epochs of human cultural evolution: the Agricultural, Industrial, and Green Revolutions.

Before the Agricultural Revolution, the size of the human population was probably less than 10 million people, who survived primarily by hunting and gathering. After plant and animal species were domesticated, the human population increased its growth rate. By about 5000 B.C.E., gains in food production caused by the Agricultural Revolution meant that the planet could support about 50 million people. For the next several thousand years, the human population continued to grow at a rate of about 0.03 percent per year. By the first year of the common era, the planet's population numbered about 300 million.

At the end of the Middle Ages, the human population numbered about 400 million. As people lived in densely populated cities, the effects of disease increased. Starting in 1348 and continuing to 1650, the human population was subjected to massive declines caused by the bubonic plague—the Black Death. At its peak in about 1400, the Black Death may have killed 25 percent of Europe's population in just over fifty years. By the end of the last great plague in 1650, the human population numbered 600 million.

The Industrial Revolution began between 1650 and 1750. Since then, the growth of the human population has increased greatly. In just under three hundred years, the earth's population went from 0.5 billion to 6 billion people, and the annual rate of increase went from 0.1 percent to 1.8 percent. This population growth was not because people were having more babies, but because more babies lived to become adults and the average adult lived a longer life.

The Green Revolution occurred in the 1960's. The development of various vaccines and antibiotics in the twentieth century and the spread of their use to most of the world after World War II caused big drops in the death rate, increasing population growth rates. Feeding this growing population has presented a challenge. This third revolution is called the Green Revolution because of the technology used to increase the amount of food produced by farms. However, the Green Revolution was really a combination of improvements in health care, medicine, and sanitation, in addition to an increase in food production.

Geography of Human Population Growth. The present-day human race traces its lineage to Africa. Humans migrated from Africa to the Middle East, Europe, Asia, and eventually to Australia, North and South America, and the Pacific Islands. It is believed that during the last Ice Age, the world's sea levels were lower because much of the world's water was trapped in ice sheets. This lower sea level created land bridges that facilitated many of the major human migrations across the world.

Patterns of human settlement are not random. People generally avoid living in deserts because they lack water. Few humans are found above the Arctic Circle because of that region's severely cold climate. Environmental factors, such as the availability of water and food and the livability of climate, influence where humans choose to live. How much these factors influence the evolution and development of human societies is a subject of debate.

The domestication of plants and animals that resulted from the Agricultural Revolution did not take place everywhere on the earth. In many parts of the world, humans remained as hunter-gatherers while agriculture developed in other parts of the world. Eventually, the agriculturalists outbred the hunter-gatherers, and few hunter-gatherers remain in the twenty-first century. Early agricultural sites have been found in many places, including Central and South America, Southeast Asia and China, and along the Tigris and Euphrates Rivers in what is now Iraq. The practice of agriculture spread from these areas throughout most of the world.

By the time Christopher Columbus reached the Americas in the late fifteenth century, there were millions of Native Americans living in towns and villages and practicing agriculture. Most of them died from diseases that were brought by European colonists. Colonization, disease, and war are major mechanisms that have changed the composition and distribution of the world's population in the last three hundred years.

The last few centuries also produced another change in the geography of the human population. During this period, the concentration of industry in urban areas and the efficiency gains of modern agricultural machinery caused large numbers of people to move from rural areas to cities to find jobs. From 1900 to 2000 the percentage of people living in cities went from 14 percent to just about 50 percent. Demographers estimate that by the year 2025, more than 60 percent of the earth's population will live in cities. Scientists estimate that the human population will continue to increase until the year 2050, at which time it will level out at between eight and fifteen billion.

Earth's Carrying Capacity. Many people are concerned that the earth cannot grow enough food or provide enough other resources to support fifteen billion people. There is great debate about the concept of the earth's carrying capacity—the maximum human population that the earth can support indefinitely. Answers to questions about the earth's carrying capacity must account for variations in human behavior. For example, the earth could support more bicycle-riding vegetarians than car-driving carnivores. Questions about carrying capacity and the environ-

In countries with large populations and limited space and resources, bicycles are a sensible alternative to automobiles for transportation. (PhotoDisc) mental impacts of the human race on the planet are fundamental to the United Nations' goals of sustainable development. Dealing with these questions will be one of the major challenges of the twenty-first century.

Paul C. Sutton

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Global Urbanization

Urbanization is the process of building and living in cities. Although the human impulse to live in groups sharing a "home base" probably dates back to cave-dweller times or before, the creation of towns and cities with a few hundred to many thousands to millions of inhabitants, required several other developments.

Foremost of these was the invention of agriculture. Tilling crops requires a permanent living place near the cultivated land. The first agricultural villages were small. Jarmo, a village site from c. 7000 B.C.E., located in the Zagros Mountains of present-day Iran, appears to have had only twenty to twenty-five houses. Still, farmers' crops and livestock provided a food surplus that could be stored in the village or traded for other goods. Surplus food also meant surplus time, enabling some people to specialize in producing other useful items, or to engage in less tangible things like religious rituals or recordkeeping.

Given these conditions, it took people with foresight and political talents to lead the process of city formation. Once in cities, however, the inhabitants found many benefits. Walls and guards provided more security than the open country. Cities had regular markets where local craftsmen and traveling merchants displayed a variety of goods. City governments often provided amenities like primitive street lighting and sanitary facilities. The faster pace of life, and the exchange of ideas from diverse people interacting, made city life more interesting and speeded up the processes of social change and invention. Writing, law, and money all evolved in the earliest cities.

Ancient and Medieval Cities. Cities seem to have appeared almost simultaneously, around 3500 B.C.E., in three separate regions. In the Fertile Crescent, a wide curve of land stretching from the Persian gulf to the northwest Mediterranean Sea, the cities of Ur, Akkad, and Babylon rose, flourished, and succeeded one another. In Egypt, a connected chain of cities grew, soon unified by a ruler using Memphis, just south of the Nile River's delta, as his strategic and ceremonial base. On the Indian subcontinent, Mohenjo-Daro and Harappa oversaw about a hundred smaller towns in the Indus River valley. Similar developments took place about a thousand years later in northern China.

These first city sites were in the valleys of great river systems, where rich alluvial soil boosted large-scale food production. The rivers served as a "water highway" for ships carrying commodities and luxury items to and from the cities. They also furnished water for drinking, irrigation, and waste disposal. Even the rivers' rampages promoted civilization, as making flood control and irrigation systems required practical engineering, an organized workforce, and ongoing political authority to direct them.

Eurasia was still full of peoples who were not urbanized, however, and who lived by herding, pirating, or raiding. Early cities declined or disappeared, in some cases destroyed by invasions from such forces around 1200 B.C.E. Afterward, the cities of Greece became newly important. Their surrounding land was poor, but their access to the sea was an advantage. Greek cities prospered from fishing and trade. They also developed a new idea, the city-state, run by and for its citizens.

Rome, the Greek cities' successor to power, reached a new level of urbanization. Its rise owed more to historical accident and its citizens' political and military talents than to location, but some geographical features are salient. In some ways, the fertile coastal plain of Latium was an ideal site for a great city, central to both the Italian peninsula and the Mediterranean Sea. There, the Tiber River becomes navigible and crossable.

In other ways, Rome's site was far from ideal. Its lower areas were swampy and mosquito-ridden. The seven hills, with their sacred sites later filled with public buildings and luxury houses, imposed a crazy-quilt pattern on the city's growth. Romans built cities with a simple rectangular plan all over Europe and the Middle East, but their home city grew in a less rational way.

At its peak, Rome had a million residents, a size no other city reached before nineteenth century London. It provided facilities found in modern cities: a piped water supply, a sewage disposal system, a police force, public buildings, entertainment districts, shops, inns, restaurants, and taverns. The streets were crowded and noisy; to control traffic, wheeled wagons could make deliveries only at night. Fire and building collapse were constant risks in the cheaply built apartment structures that housed the city's poorer residents. Still, few wanted to live anywhere but in Rome, their world's preeminent city.

In the Dark Ages after the western Roman Empire collapsed, feudalism, based on land holdings, eclipsed urban life. Cities never disappeared, but their populations and services declined drastically. Urban life still flourished for another millenium in the eastern capital of Constantinople. When Islam spread across the Middle East, it caused the growth of new cities, centered around a mosque and a marketplace.

In the twelfth and thirteenth centuries, life revived in Western Europe. As in the Islamic cities, the driving forces were religious—the building of cathedrals—and commercial—merchants and artisans expanding the reach of their activities. Medieval cities were usually walled, with narrow twisting streets and a lack of basic sanitary measures, but they drew ambitious people and innovative forces together. Italy's cities revived the concept of the city-state with its outward reach. Venice sent its merchant fleet all over the known world. Farther north, Paris and Bologna hosted the first universities. As the feudal system slowly gave way to nation-states ruled by one king, the cities generally supported the latter.

Modern Cities. Modern cities differ from earlier ones because of changes wrought by technology, but most of today's cities arose before the Industrial Revolution. Until the early nineteenth century, travel within a city was by foot or on horse, which limited street widths and city sizes. The first effect of railroads was to shorten travel time between cities. This helped country residents moving to the cities, and speeded raw materials going into and manufactured goods coming out of the factories that increasingly dotted urban areas. Rail transit soon caused the growth of a suburban ring. Prosperous city workers could live in more spacious homes outside the city, riding rail lines to work every day. This pattern was common in London and New York City.

Factories, the lifeblood of the Industrial Revolution, were built in pockets of existing cities. Smaller cities like Glasgow, Scotland, and Pittsburgh, Pennsylvania, grew as ironworking industries, using nearby or easily transported coal and ore resources, built large foundries there. Neither industrialists nor city authorities worried about where the people working there would live. Workers took whatever housing they could find in tenements or subdivided old mansions.

Beginning in the 1880's, metal-framed construction made taller buildings possible. These skyscrapers towered over stately three- to eight-story structures of an earlier period. Because this technology enabled expensive central-city ground space to house many profitable office suites, up through the 1930's, city cores became quite compacted. Many people believed such skyward growth was the wave of the future and warned that city streets were becoming sunless, dangerous canyons.

Automobiles kept these predictions from fully coming true. As car ownership became widespread, more roads were built or widened to carry the traffic. Urban areas began to decentralize. The car, like rail transit before it, allowed people to flee the urban core for suburban living. Because roads could be built almost anywhere, built-up areas around cities came to resemble large patches filling a circle, rather than the spokes-of-a-wheel pattern introduced by rail lines. Cities born during the

Urbanization and Developing Nations

The urban population, or number of people living in cities, in North America accounts for about 75 percent of its total population. In Europe, about 90 percent of the population lives in cities. In developing countries, the urban population is often less than 30 percent. The term "urbanization" refers to the rate of population growth of cities. Urbanization mainly results from people moving to cities from elsewhere. In developing countries, the urbanization rate is very high compared to those of North America or Europe. The high rate of urbanization of these countries makes it difficult for their governments to provide housing, water, sewers, jobs, schools, and other services for their fast-growing urban populations.

automotive age tend to have an indistinct city center, surrounded by large areas of diffuse urban development. The prime example is Los Angeles, California: It has a small downtown area, but a consolidated metropolitan area of about 34,000 square miles (88,000 sq. km.).

Almost everywhere, urban sprawl has created satellite cities with major manufacturing, office, and shopping nodes. These cause an increasing portion of daily travel within metropolitan areas to be between one edge city and another, rather than to and from downtown. Since these journeys have an almost limitless variety of start points and destinations within the urban region, mass transit is only a partial solution to highway crowding and air pollution problems.

The above trends typify the so-called developed world, especially the United States. Many cities in poor nations have grown even more rapidly but with a different mix of patterns and problems. However, the basic pattern can be detected around the globe, as urban dwellers seek to better their own circumstances.

Megacities and the Future. In the year 2000 the world had twenty-one megacities, defined as urban areas with a population of 10 million or more. The largest was Tokyo, with an estimated 27 million people in 1995, predicted to grow to around 29 million in 2015. Second largest was Mexico City, with more than 16 million in 1995 and annual growth at 1.81 percent. New York at 16 million and Los Angeles at 12 million are North America's other megacities. In the first half of the 1990's, Los Angeles grew 1.6 per cent annually, much of it from international migration to the region.

Megacities profoundly affect the air, weather, and terrain of their surrounding territory. Smog is a feature of urban life almost everywhere, but is worse where the exhaust from millions of cars mixes with industrial pollution. Some megacities have slowed the problem by regulating combustion technology; none has solved it. Huge expanses of soil preempted by

Urban Heat Islands

Large cities have distinctly different climates from the rural areas that surround them. The most important climatic characteristic of a city is the urban heat island, a concentration of relatively warmer temperatures, especially at nighttime. Large cities are frequently at least 11 degrees Fahrenheit (6 degrees Celsius) warmer than the surrounding countryside.

The urban heat island results from several factors. Primary among these are human activities, such as heating homes and operating factories and vehicles, that produce and release large quantities of energy to the atmosphere. Most of these activities involve the burning of fossil fuels such as oil, gas, and coal. A second factor is the abundance of heat-absorbing urban materials, such as brick, concrete, and asphalt. A third factor is the surface dryness of a city. Urban surface materials normally absorb little water and therefore quickly dry out after a storm. In contrast, the evaporation of moisture from wet soil and vegetation in rural areas uses a large quantity of solar energy—often more than is converted directly to heat—resulting in cooler air temperatures and higher relative humidities.

buildings and pavements can turn heavy rains into floods almost instantly, and the ambient heat in large cities stays several degrees higher than in comparable rural areas. Recent engineering studies suggest that megacities create instability in the ground beneath, compressing and undermining it.

How will cities evolve? Barring an unforeseen technological or social breakthrough—which could happen in the twenty-first century—the current growth and problems will probably continue. The process of megapolis—metropolitan areas blending together along the corridors between them—is well underway in many areas. Predictions that the computer will so change the nature of work as to cause massive population shifts away from cities have proven premature. Despite its drawbacks, increasing numbers of people are drawn to urban life, seeking the economic opportunities and wider social world that cities offer.

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Global Time and Time Zones

Before the nineteenth century, people kept time by local reckoning of the position of the Sun; consequently, thousands of local times existed. In medieval Europe, "hours" varied in length, depending upon the seasons: Each hour was determined by the Roman Catholic Church. In the sixteenth century, Holy Roman emperor Charles V was the first secular ruler to decree hours to be of equal length. As the industrial and scientific revolutions swept Europe, North America, and other areas, some form of time standardization became necessary as communities and regions increasingly interacted. In 1780 Geneva, Switzerland, was the first locality known to employ a standard time, set by the town-hall clockkeeper, throughout the town and its immediate vicinity.

The growth and expansion of railroads, providing the first relatively fast movement of people and goods from city to city, underscored the need for a standard system in Great Britain. As early as 1828, Sir John Herschel, Astronomer Royal, called for a national standard time system based on instruments at the Royal Observatory at Greenwich. That practice began in 1852, when the British telegraph system had developed sufficiently for the Greenwich time signals to be sent instantly to any point in the country.

As railroads expanded through North America, they exposed a problem of local time variation similar to that in Great Britain but on a far larger scale, since the distances between the East and West Coasts were much greater than in Great Britain. In order for long-distance train schedules to work, different parts of the country had to coordinate their clocks. The first to suggest a standard time framework for the United States was Charles F. Dowd, president of Temple Grove Seminary for Women in Saratoga Springs, New York. Initially, Dowd proposed putting all U.S. railroads on a single standard time, based on the time in Washington, D.C. When he realized that the time in California would be behind such a standard by almost four hours, he produced a revised system, establishing four time zones in the United States. Dowd's plan, published in 1870, included the first known map of a time zone system for the country.

Not everyone was happy with the designation of Washington, D.C., as the administrative center of time in the United States. Northeastern railroad executives urged that New York, the commercial capital of the nation, be used instead: Many cities and towns in the region already had standardized to New York time out of practical necessity. Dowd proposed a compromise: to set the entire national time zone system in the United States using the Greenwich prime meridian, already in use in many parts of the world for maritime and scientific purposes. In 1873 the American Association of Railways (AAR) flatly rejected the proposal.

In the end, Dowd proved to be a visionary. In 1878 Sandford Fleming, chief engineer of the government of Canada, proposed a worldwide system of twenty-four time zones, each fifteen degrees of longitude in width, and each bisected by a meridian, beginning with the prime meridian of Greenwich. William F. Allen, general secretary of the AAR and armed with a deep knowledge of railroad practices and politics, took up the crusade and persuaded the railroads to agree to a system. At noon on Sunday, November 18, 1883, most of the more than six hundred U.S. railroad lines dropped the fifty-three arbitrary times they had been using and adopted Greenwich-indexed meridians that defined the times in each of four times zones: eastern, central, mountain, and Pacific. Most major cities in the United States and Canada followed suit.

Time System for the World. Almost at the same time that American railroads adopted a standard time zone system, the State Department, authorized by the United States Congress, invited governments from around the world to assemble delegates in Washington, D.C., to adopt a global system. The International Meridian Conference assembled in the autumn of 1884, attended by representatives of twenty-five countries. Led by Great Britain and the United States, most favored adoption of Greenwich as the official prime meridian and Greenwich mean time as universal time.

There were other contenders: The French wanted the prime meridian to be set in Paris, and the Germans wanted it in Berlin; others proposed a mountaintop in the Azores or the tip of the Great Pyramid in Egypt. Greenwich won handily. The conference also agreed officially to start the universal day at midnight, rather than at noon or at sunrise, as practiced in many parts of the world. Each time zone in the world eventually came to have a local name, although technically, each goes by a letter in the alphabet in order eastward from Greenwich.

Once a global system was in place, there was a new issue: Many jurisdictions wanted to adjust their clocks for part of the year to account for differences in the number of hours of daylight between summer and winter months. In 1918 Congress decreed a system of daylight saving time for the United States but almost immediately abolished it, leaving state governments and communities to their local options. Daylight saving time, or a form of it, returned in the United States and many Allied nations during World War II. In the Uniform Time Act of 1966, Congress finally established a national system of daylight saving time, although with an option for states to abstain.

To the extent that it indicates how human communities want to manipulate time for social, political, or economic reasons, the issue of daylight saving time, rather than the establishment of a system of world time zones, is a better clue to the geographical issues involved in time administration. Both the history and the present format of the world time zone system show that the mathematically precise arrangement envisioned by many of the pioneers of time zones is not as important as things on the ground.

In the United States, the railroad time system adopted in 1883 drew the boundary between eastern time and central time more or less between the thirteen original states and the trans-Appalachian West: The entire Midwest, including Ohio, Indiana, and Michigan, fell in the central time zone. As the center of population migrated westward, train speeds increased, highways developed, and New York emerged as the center of mass media in the United States, the boundary between the eastern and central time zones marched steadily westward. In 1918 it ran down the middle of Ohio; by the 1960's, it was at the outskirts of Chicago.

One of the principal reasons for the popularity of Greenwich as the site of the prime meridian (zero degrees longitude), is that it places the international date line (180 degrees longitude)—where, in effect, time has to move forward to the next day rather than the next hour—far out in the Pacific Ocean where few people are affected by what otherwise would be an awkward arrangement. However, even this line is somewhat irregular, to avoid placing a small section of eastern Russia and some of the Aleutian Islands of the United States in different days.

By 1950 most nations had adopted the universal time zone system, although a few followed later: Saudi Arabia in 1962, Liberia in 1972. Despite adhering to the system in principle, many nations take considerable liberties with the zones, especially if their territory spans several time zones. All of Western Europe, despite covering an area equivalent to two zones, remains on a single standard. The People's Republic of China, which stretches across five different time zones, arbitrarily sets the entire country officially on Beijing time, eight hours behind Greenwich. Iran, Afghanistan, India, and Myanmar, each of which straddle time zone boundaries, operate on half-hour compromise systems as their time standards (as does Newfoundland). As late as 1978, Guyana's standard time was three hours, forty-five minutes in advance of Greenwich.

It can be argued that adoption of a worldwide system of time zones in the late nineteenth century was one of the earliest manifestations of the emergence of a global economy and society, and has been a crucial factor in the unfolding of this process throughout the twentieth century and beyond.

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The Time Service Department of the United States Naval Observatory in Washington, D.C., maintains a Web site on time zones in the United States and around the world. Visitors can access a map of current world time zones, review the U.S. law on standard time zones, and inquire about local standard time for any country or region in the world.
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Climate and Human Societies

Climate and Human Settlement

According to an old saying, "Everyone talks about the weather, but nobody does anything about it." If everyone talks about the weather, it is because it is important to them—to how they feel and to how their bodies and minds function. There is plenty they can do about it, from going to a different location to creating an artificial indoor environment.

Climate. The term "climate" refers to average weather conditions over a long period of time and to the variations around that average from day to day or month to month. Temperature, air pressure, humidity, wind conditions, sunshine, and rainfall—all are important elements of climate and differ systematically with location. Temperatures tend to be higher near the equator and are so low in the polar regions that very few people live there. In any given region, temperatures are lower at higher altitudes. Areas close to large bodies of water have more stable temperatures. Rainfall depends on topography: The Pacific Coast of the United States receives a great deal of rain, but the nearby mountains prevent it from moving very far inland. Seasonal variations in temperature are larger in temperate zones.

Throughout human history, climate has affected where and how people live. People in technologically primitive cultures, lacking much protective clothing or housing, needed to live in mild climates, in environments favorable to hunting and gathering. As agricultural cultivation developed, populations located where soil fertility, topography, and climate were favorable to growing crops and raising livestock. Areas in the Middle East and near the Mediterranean Sea flourished before 1000 B.C.E. Many equatorial areas were too hot and humid for human and animal health and comfort, and too infested with insect pests and diseases.

Improvements in technology allowed settlement to range more widely north and south. Sturdy houses and stables, internal heating, and warm clothing enabled people to survive and be active in long cold winters. Some peoples developed nomadic patterns, moving with herds of animals to adapt to seasonal variations.

A major challenge in the evolution of settled agriculture was to adapt production to climate and soil conditions. In North America, such crops as cotton, tobacco, rice, and sugarcane have relatively restricted areas of cultivation. Wheat, corn, and soybeans are more widely grown, but usually further north. Winter wheat is an ingenious adaptation to climate. It is sown and germinates in autumn, then matures and is harvested the following spring. Rice, which generally grows in standing water, requires special environmental conditions.

Tropical Problems. Some scholars argue that tropical climates encourage life to flourish but do not promote quality of life. In hot climates, peo-

Ireland's Potato Famine and European Emigration

Mass migration from Europe to North America began in the 1840's after a serious blight destroyed a large part of the potato crop in Ireland and other parts of Northern Europe. The weather played a part in the famine; during the autumns of 1845 and 1846 climatic conditions were ideal for spreading the potato blight. The major cause of the famine, however, was the blight itself, and the impact was severe on low-income farmers for whom the potato was the major food.

The famine and related political disturbances led to mass emigration from Ireland and from Germany. By 1850 there were nearly a million Irish and more than half a million Germans in the United States. Combined, these two groups made up more than two-thirds of the foreign-born U.S. population of 1850. The settlement patterns of each group were very different. Most Irish were so poor they had to work for wages in cities or in construction of canals and railroads. Many Germans took up farming in areas similar in climate and soil conditions to their homelands, moving to Wisconsin, Minnesota, and the Dakotas.

ple do not need much caloric intake to maintain body heat. Clothing and housing do not need to protect people from the cold. Where temperatures never fall below freezing, crops can be grown all year round. Large numbers of people can survive even where productivity is not high. However, hot humid conditions are not favorable to human exertion. Some tropical areas, such as South India, Bangladesh, Indonesia, and Central Africa, have developed large populations living at relatively low levels of income.

Slavery. Efforts to develop tropical regions played an important part in the rise of the slave trade after 1500 C.E. Black Africans were kidnapped and forceably transported to work in hot, humid regions. The West Indian islands became an important location for slave labor, particularly in sugar production. On the North American continent, slave labor was important for producing rice, indigo, and tobacco in colonial times. All these were eclipsed by the enormous growth of cotton production in the early years of U.S. independence. It has been estimated that the forced migration of Africans to the Americas involved about 1,800 Africans per year from 1450 to 1600, 13,400 per year in the seventeenth century, and 55,000 per year from 1701 to 1810. Estimates vary wildly, but at least 7.7 million Africans were forced to migrate in this process.

European Migration. Migration of European peoples also accelerated after the discovery of the New World. They settled mainly in temperate-zone regions, particularly North America. Although Great Britain gained colonial dominion over India, the Netherlands over present-day Indonesia, and Belgium over a vast part of central Africa, few Europeans went to those places to live. However, many Chinese migrated throughout the Nanyang (South Sea) region, becoming commercial leaders in present-day Malaysia, Thailand, Indonesia, and the Philippines, despite the heat and humidity. British emigrants settled in Australia and New Zealand, Spanish and Italians in Argentina, Dutch (Boers) in South Africa—all temperate regions.

Climate and Economics. Most of the economic progress of the world between 1492 and 2000 occurred in the temperate zones, primarily in Europe and North America. Climatic conditions favored agricultural productivity. Some scholars believe that these areas had climatic conditions that were stimulating to intellectual and technological development. They argue that people are invigorated by seasonal variation in temperature, sunshine, rain, and snow. Storms—particularly thunderstorms—can be especially stimulating, as many parents of young children have observed for themselves.

Climate has contributed to the great economic productivity of the United States. This productivity has attracted a flow of immigrants, which averaged about one million a year from 1905 to 1914. Immigration approached that level again in the 1990's, as large numbers of Mexicans crossed the southern border of the United States, often coming for jobs

Orchard heaters are an example of human adaptation to climate. Designed to keep valuable fruits from being spoiled during cold snaps, they make it possible to grow plants in regions where climatic conditions are generally good, but where a single period of freezing temperatures can destroy an entire season's crop. (PhotoDisc)

as agricultural laborers in the hot conditions of the Southwest—a climate that made such work unattractive to many others.

Unpredictable climate variability was important in the peopling of North America. During the 1870's and 1880's, unusually favorable weather encouraged a large flow of migration into the grain-producing areas just west of the one-hundredth meridian. Then came severe drought and much agrarian distress. Between 1880 and 1890, the combined population of Kansas and Nebraska increased by about a million, an increase of 72 percent. During the 1890's, however, their combined population was virtually constant, indicating that a large out-migration was offsetting the natural increase. Much of the area reverted to pasture, as climate and soil conditions could not sustain the grain production that had attracted so many earlier settlers.

Climate variability can be a serious hazard. Freezing temperatures for more than a few hours during spring can seriously damage fruits and vegetables. A few days of heavy rain can produce serious flooding.

Recreation and Retirement. Whenever people have been able to separate decisions about where to live from decisions about where to work, they have gravitated toward pleasant climatic conditions. Vacationers head for Caribbean islands, Hawaii, the Crimea, the Mediterranean Coast, even the Baltic coast. "The mountains" and "the seashore" are attractive the world over. Paradoxically, some of these areas (the Caribbean, for instance) have monotonous weather year-round and thus have not attracted large inflows of permanent residents. Winter sports have created popular resorts such as Vail and Aspen in Colorado, and numerous older counterparts in New England. Large numbers of Americans have retired to the warm climates in Florida, California, and Arizona. These areas then attract working-age adults who earn a living serving vacationers and retirees. Since these locations are uncomfortably hot in summer, their attractiveness for residence had to await the coming of air conditioning in the latter part of the twentieth century.

Human Impact on Climate. Climate interacts with pollution. Bad-smelling factories and refineries have long relied on the wind to disperse atmospheric pollutants. The city of Los Angeles, California, is uniquely vulnerable to atmospheric pollution because of its topography and wind currents. Government regulations of automobile emissions have had to be much more stringent there than in other areas to keep pollution under control.

Human activities have sometimes altered the climate. Development of a large city substitutes buildings and pavements for grass and trees, raising summer temperatures and changing patterns of water evaporation. Atmospheric pollutants have contributed to acid rain, which damages vegetation and pollutes water resources. Many observers have also blamed human activities for a trend toward global warming. Much of this has been blamed on carbon dioxide generated by combustion, particularly of fossil fuels. A widespread rise in temperatures could be expected to raise water levels in the oceans as polar icecaps melt and change the relative attractiveness of many locations.

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Flood Control

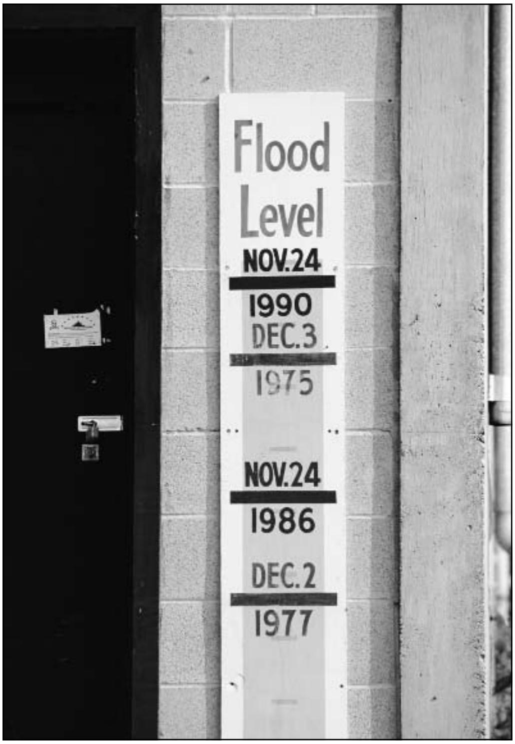
Flood control presents one of the most daunting challenges humanity faces. The regions that human communities have generally found most desirable, for both agriculture and industry, have also been the lands at greatest risk of experiencing devastating floods. Early civilization developed along river valleys and in coastal floodplains because those lands contained the most fertile, most easily irrigated soils for agriculture, combined with the convenience of water transportation.

The Nile River in North Africa, the Ganges River on the Indian subcontinent, and the Yangtze River in China all witnessed the emergence of civilizations that relied on those rivers for their growth. People learned quickly that living in such areas meant living with the regular occurrence of life-threatening floods.

Knowledge that floods would come did not lead immediately to attempts to prevent them. For thousands of years, attempts at flood control were rare. The people living along river valleys and in floodplains often developed elaborate systems of irrigation canals to take advantage of the available water for agriculture and became adept at using rivers for transportation, but they did not try to control the river itself. For millennia, people viewed periodic flooding as inevitable, a force of nature over which they had no control. In Egypt, for example, early people learned how far out over the riverbanks the annual flooding of the Nile River would spread and accommodated their society to the river's seasonal patterns. Villagers built their homes on the edge of the desert, beyond the reach of the flood waters, while the land between the towns and the river became the area where farmers planted crops or grazed livestock.

In other regions of the world, buildings were placed on high foundations or built with two stories on the assumption that the local rivers would regularly overflow their banks. In Southeast Asian countries such as Thailand and Vietnam, it is common to see houses constructed on high wooden posts above the rivers' edge. The inhabitants have learned to allow for the water levels' seasonal changes.

Flood Control Structures. Eventually, societies began to try to control floods rather than merely survive them. Levees and dikes—earthen embankments constructed to prevent water from flowing into low-lying areas—were built to force river waters to remain within their channels



Marker showing flood levels previously reached in an urban area. (PhotoDisc)

rather than spill out over a floodplain. Flood channels or canals that fill with water only during times of flooding, diverting water away from populated areas, are also a common component of flood control systems. Areas that are particularly susceptible to flash floods have constructed numerous flood channels to prevent flooding in the city. For example, for much of the year, Southern California's Los Angeles River is a small stream flowing down the middle of an enormous, 20- to 30-foot-deep (6- to 9-meter) concrete-lined channel, but winter rains can fill its bed from bank to bank. Flood channels prevent the river from washing out neighborhoods and freeways.

Engineers designed dams with reservoirs to prevent annual rains or snowmelt entering the river upstream from running into populated areas. By the end of the twentieth century, extremely complex flood control systems of dams, dikes, levees, and flood channels were common. Patterns of flooding that had existed for thousands of years ended as civil engineers attempted to dominate natural forces.

The annual inundation of the Egyptian delta by the flood waters of the Nile River ceased in 1968 following construction of the 365-foot-high (111 meters) Aswan High Dam. The reservoir behind the 3,280-foot-long (1,000-meter) dam forms a lake almost ten miles (16 km.) wide and almost three hundred miles (480 km.) long. Flood waters are now trapped behind the dam and released gradually over a year's time.

Environmental Concerns. Such high dams are increasingly being questioned as a viable solution for flood control. The Three Gorges Dam being constructed in China at the end of the twentieth century may be the last high dam constructed for the purpose of flood control. As human understanding of both hydrology and ecology have improved, the disruptive effects of flood control projects such as high dams, levees, and other engineering projects are being examined more closely.

Hydrologists and other scientists who study the behavior of water in rivers and soils have long known that vegetation and soil types in watersheds can have a profound effect on downstream flooding. The removal of forest cover through logging or clearing for agriculture can lead to severe flooding in the future. Often that flooding will occur many miles downstream from the logging activity. Devastating floods in the South Asian country of Bangladesh, for example, have been blamed in part on clear-cutting of forested hillsides in the Himalaya Mountains in India and Nepal. Monsoon rains that once were absorbed or slowed by forests now run quickly off mountainsides, causing rivers to reach unprecedented flood levels. Concerns about cause-and-effect relationships between logging and flood control in the mountains of the United States were one reason for the creation of the U.S. Forest Service in the nineteenth century.

In populated areas, even seemingly trivial events such as the construction of a shopping center parking lot can affect flood runoff. When thousands of square feet of land are paved, all the water from rain runs into storm drains rather than being absorbed slowly into the soil and then filtered through the watertable. Engineers have learned to include catch basins, either hidden underground or openly visible but disguised as landscaping features such as ponds, when planning a large paving project.

Wetlands and Flooding. Less well known than the influence of watersheds on flooding is the impact of wetlands along rivers. Many river sys-

In populated areas, where many square miles of land are paved, rainwater flows into storm drains rather than being absorbed into the soil. When the storm drains reach capacity, flooding occurs. (PhotoDisc)

Urban flooding. (PhotoDisc)

tems are bordered by long stretches of marsh and bog. In the past, flood control agencies often allowed farmers to drain these areas for use in agriculture and then built levees and dikes to hold the river within a narrow channel. Scientists now know that these wetlands actually serve as giant sponges in the flood cycle. Flood waters coming down a river would spread out into wetlands and be held there, much like water is trapped in a sponge.

Draining wetlands not only removes these natural flood control areas but worsens flooding problems by allowing floodwater to precede downstream faster. Even if life-threatening or property-damaging floods do not occur, faster-flowing water significantly changes the ecology of the river system. Waterborne silt and debris will be carried farther. Trying to control floods on the Mississippi River has had the unintended consequence of causing waterborne silt to be carried farther out into the Gulf of Mexico by the river, rather than be deposited in the delta region. This, in turn, has led to the loss of shore land as ocean wave actions wash soil away, but no new alluvial deposits arrive to replace it.

In any river system, some species of aquatic life will disappear and others replace them as the speed of flow of the water affects water temperature and the amount of dissolved oxygen available for fish. Warm-water fish such as bass will be replaced by cold-water fish such as trout, or vice versa. Biologists estimate that more than twenty species of freshwater mussels have vanished from the Tennessee River since construction of a series of flood control and hydroelectric power generation dams have turned a fast-moving river into a series of slow-moving reservoirs.

Future of Flood Control. By the end of the twentieth century, engineers increasingly recognized the limitations of human interventions in flood control. Following devastating floods in the early 1990's in the Mississippi River drainage, the U.S. Army Corps of Engineers recommended that many towns that had stood right at the river's edge be moved to higher ground. That is, rather than trying to prevent a future flood, the Corps advised citizens to recognize that one would inevitably occur, and that they should remove themselves from its path. In the United States and a number of other countries, land that has been zoned as floodplains can no longer be developed for residential use. While there are many things humanity can do to help prevent floods, such as maintaining well-forested watersheds and preserving wetlands, true flood control is probably impossible. Dams, levees, and dikes can slow the water down, but eventually, the water always wins.

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Atmospheric Pollution

Pollution of the earth's atmosphere comes from many sources. Some forces are natural, such as volcanoes and lightning-caused forest fires, but most sources of pollution are byproducts of industrial society. Atmospheric pollution cannot be confined by national boundaries; pollution generated in one country often spills over into another country, as is the case for acid deposition, or acid rain, generated in the midwestern states of the United States that affects lakes in Canada.

Major Air Pollutants. Each of eight major forms of air pollution has an impact on the atmosphere. Often two or more forms of pollution have a combined impact that exceeds the impact of the two acting separately.

These eight forms are:

1. Suspended particulate matter: This is a mixture of solid particles and aerosols suspended in the air. These particles can have a harmful impact on human respiratory functions.

2. Carbon monoxide (CO): An invisible, colorless gas that is highly poisonous to air-breathing animals.

3. Nitrogen oxides: These include several forms of nitrogen-oxygen compounds that are converted to nitric acid in the atmosphere and are a major source of acid deposition.

4. Sulfur oxides, mainly sulfur dioxide: This sulfur-oxygen compound is converted to sulfuric acid in the atmosphere and is another source of acid deposition.

5. Volatile organic compounds: These include such materials as gasoline and organic cleaning solvents, which evaporate and enter the air in a vapor state. VOCs are a major source of ozone formation in the lower atmosphere.

6. Ozone and other petrochemical oxidants: Ground-level ozone is highly toxic to animals and plants. Ozone in the upper atmosphere, however, helps to shield living creatures from ultraviolet radiation.

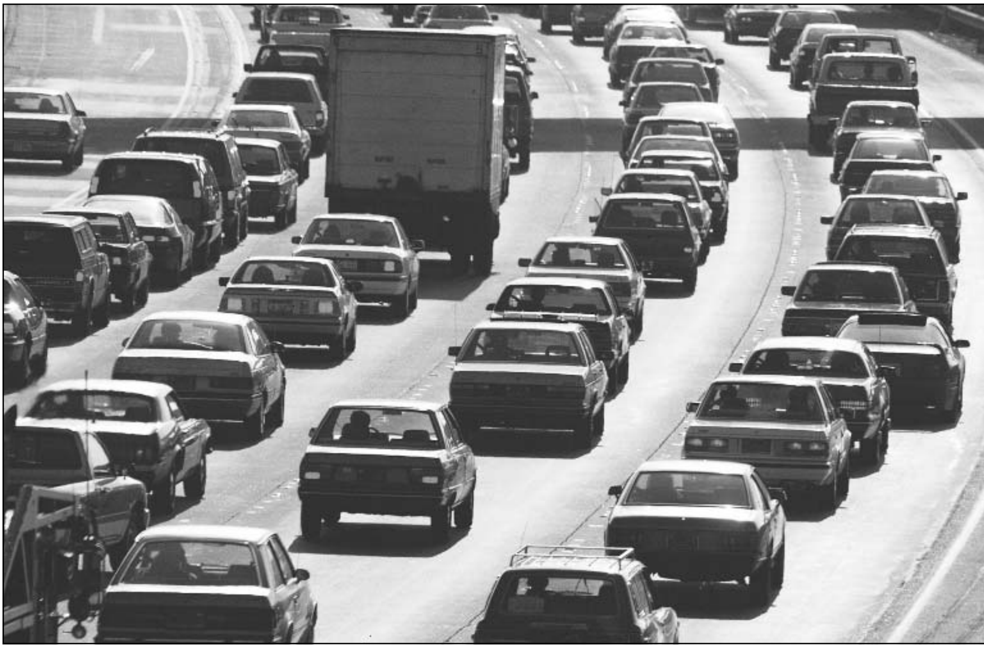
7. Lead and other heavy metals: Generated by various industrial processes, lead is harmful to human health even at very low concentrations.

8. Air toxics and radon: Examples include cancer-causing agents, radioactive materials, or asbestos. Radon is a radioactive gas produced by natural processes in the earth.

All eight forms of pollution can have adverse effects on human, animal, and plant life. Some, such as lead, can have a very harmful effect over a small range. Others, such as sulfur and nitrogen oxides, can cross national boundaries as they enter the atmosphere and are carried many miles by prevailing wind currents. For example, the radioactive discharge from the explosion of the Chernobyl nuclear plant in the former Soviet Union in 1986 had harmful impacts in many countries. Atmospheric radiation generated by the explosion rapidly spread over much of the Northern Hemisphere, especially the countries of northern Europe.

Impacts of Atmospheric Pollution. Atmospheric pollution not only has a direct impact on the health of humans, animals, and plants but also affects life in more subtle, often long-term, ways. It also affects the economic well-being of people and nations and complicates political life.

Atmospheric pollution can kill quickly, as was the case with the killer smog, brought about by a temperature inversion, that struck London in 1952 and led to more than four thousand pollution-related deaths. In the late 1990's, the atmosphere of Mexico City was so polluted from automobile exhausts and industrial pollution that sidewalk stands selling pure oxygen to people with breathing problems became thriving businesses. Many of the heavy metals and organic constituents of air pollution can cause cancer when people are exposed to large doses or for long periods



Emissions from motor vehicles are the leading contributors to atmospheric pollution in most urban centers. (PhotoDisc)

of time. Exposure to radioactivity in the atmosphere can also increase the likelihood of cancer.

In some parts of Germany and Scandinavia in the 1990's, as well as places in southern Canada and the southern Appalachians in the United States, certain types of trees began dying. There are several possible reasons for this die-off of forests, but one potential culprit is acid deposition. As noted above, one byproduct of burning fossil fuels (for example, in coal-fired electric power plants) is the sulfur and nitrous oxides emitted from the smokestacks. Once in the atmosphere, these gases can be carried for many miles and produce sulfuric and nitric acids.

These acids combine with rain and snow to produce acidic precipitation. Acid deposition harms crops and forests and can make a lake so acidic that aquatic life cannot exist in it. Forests stressed by contact with acid deposition can become more susceptible to damage by insects and other pathogens. Ozone generated from automobile emissions also kills many plants and causes human respiratory problems in urban areas.

Air pollution also has an impact on the quality of life. Acid pollutants have damaged many monuments and building facades in urban areas in Europe and the United States. By the late 1990's, the distance that people could see in some regions, such as the Appalachians, was reduced drastically because of air pollution.

Global Warming

An aspect of atmospheric pollution is the potential impact that several pollutants have on the world's climate. Carbon dioxide, methane, water vapor, and other trace gases are labeled "greenhouse gases" because they act like glass in a greenhouse, blanketing and insulating the earth and slowing radiational cooling. Atmospheric carbon dioxide has increased, largely because of the burning of fossil fuels, which also contributes to other forms of atmospheric pollution.

Trace gases of particular importance are synthetic chlorofluorocarbons (CFCs), by-products of aerosols and some forms of refrigerants used for air conditioning. CFCs deplete ozone in the stratosphere, allowing increased ultraviolet radiation to reach the earth. The amount of CFCs in the atmosphere has been declining since the industrial nations signed the Montreal Accord of 1987, calling for a dramatic reduction in their use. However, CFCs still pose a problem because they remain in the stratosphere for many years. Presently, there are holes in the ozone layer of the stratosphere over both the Arctic and the Antarctic.

The economic impact of air pollution may not be as readily apparent as dying trees or someone with a respiratory ailment, but it is just as real. Crop damage reduces agricultural yield and helps to drive up the cost of food. The costs of repairing buildings or monuments damaged by acid rain are substantial. Increased health-care claims resulting from exposure to air pollution are hard to measure but are a cost to society nevertheless.

It is impossible to predict the potential for harm from rapid global warming arising from greenhouse gases and the destruction of the ozone layer by chlorofluorocarbons (CFCs), but it could be catastrophic. Rapid global warming would cause the sea level to rise because of the melting of the polar ice caps. Low-lying coastal areas would be flooded, or, in the case of Bangladesh, much of the country. Global warming would also change crop patterns for much of the world.

Solutions for Atmospheric Pollution. Although there is still some debate, especially among political leaders, most scientists recognize that air pollution is a problem that affects both the industrialized and developing world. In their rush to industrialize, many nations begin generating substantial amounts of air pollution; China's extensive use of coal-fired power plants is just one example.

The major industrial nations are the primary contributors to atmospheric pollution. North America, Europe, and East Asia produce 60 percent of the world's air pollution and 60 percent of its food supply. Because of their role in supplying food for many other nations, anything that damages their ability to grow crops hurts the rest of the world.

Many industrialized nations are making efforts to control air pollution, for example, the Clean Air Act of 1970 in the United States or the international Montreal Accord to curtail CFC production. Progress is slow and the costs of reducing air pollution are often high. In the year 2000 the record of the nations of the world in dealing with air pollution was a mixed one. There were some signs of progress, such as reduced automobile emissions and sulfur and nitrous oxides in industrialized nations, but acid deposition remains a problem in some areas. CFC production has been halted, but the impact of CFCs on the ozone layer will continue for many years. However, more nations are becoming aware of the health and economic impact of air pollution and are working to keep the problem from getting worse.

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Modern chemical plant. In their rush to industrialize, many developing nations have begun generating substantial amounts of air pollution. However, the major industrial nations are the primary contributors to atmospheric pollution. North America, Europe, and East Asia produce 60 percent of the world's air pollution. (PhotoDisc)

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Disease and Climate

Climate influences the spread and persistence of many diseases, such as tuberculosis and influenza, which thrive in cold climates, and malaria and encephalitis, which are limited by the warmth and humidity that sustains the mosquitoes carrying them. Because the earth is warming as a result of the generation of carbon dioxide and other "greenhouse gases" from the burning of fossil fuels, there is intensified scientific concern that warm-weather diseases will reemerge as a major health threat in the near future.

Scientific Findings. The question of whether the earth is warming as a result of human activity was settled in scientific circles in 1995, when the Second Assessment Report of the Intergovernmental Panel on Climate Change, a worldwide group of about twenty-five hundred experts, was issued. The panel concluded that the earth's temperature had increased between 0.5 to 1.1 degrees Fahrenheit (0.3 to 0.6 degrees Celsius) since reliable worldwide records first became available in the late nineteenth century. Furthermore, the intensity of warming had increased over time. By the 1990's, the temperature was rising at the most rapid rate in at least ten thousand years.

The Intergovernmental Panel concluded that human activity—the increased generation of carbon dioxide and other "greenhouse gases"—is responsible for the accelerating rise in global temperatures. The amount of carbon dioxide in the atmosphere has risen nearly every year because of increased use of fossil fuels by ever-larger human populations experiencing higher living standards.

In 1998, Paul Epstein of the Harvard School of Public Health described the spread of malaria and dengue fever to higher altitudes in tropical areas of the earth as a result of warmer temperatures. Rising winter temperatures have allowed disease-bearing insects to survive in areas that could not support them previously. According to Epstein, frequent flooding, which is associated with warmer temperatures, also promotes the growth of fungus and provides excellent breeding grounds for large numbers of mosquitoes. Some experts cite the flooding caused by Hurricane Floyd and other storms in North Carolina during 1999 as an example of how global warming promotes conditions ideal for the spread of diseases imported from the Tropics.

Heat, Humidity, and Disease. During the middle 1990's, an explosion of termites, mosquitoes, and cockroaches hit New Orleans, following anunprecedented five years without frost. At the same time, dengue fever spread from Mexico across the border into Texas for the first time since records have been kept. Dengue fever, like malaria, is carried by a mosquito that is limited by temperature and humidity. Colombia was experiencing plagues of mosquitoes and outbreaks of the diseases they carry, including dengue fever and encephalitis, triggered by a record heat wave followed by heavy rains. In 1997 Italy also had an outbreak of malaria.

The global temperature is undeniably rising. According to the National Oceanic and Atmospheric Administration, July, 1998, was the hottest month since reliable worldwide records have been kept, or about 150 years. The previous record had been set in July, 1995.

The rising incidence of some respiratory diseases may be related to a warmer, more humid environment. The American Lung Association reported that more than fifty-six hundred people died of asthma in the United States during 1995, a 45.3 percent increase in mortality over ten years, and a 75 percent increase since 1980. Roughly a third of those cases occurred in children under the age of eighteen. Asthma is now one of the leading diseases among the young. Since 1980, there has been a 160 percent increase in asthma in children under the age of five.

Heat Waves and Health. A study by the Sierra Club found that air pollution, which will be enhanced by global warming, could be responsible for many human health problems, including respiratory diseases such as asthma, bronchitis, and pneumonia.

According to Joel Schwartz, an epidemiologist at Harvard University, air pollution concentrations in the late 1990's were responsible for 70,000 early deaths per year and more than 100,000 excess hospitalizations for heart and lung disease in the United States. Global warming could cause these numbers to increase 10 to 20 percent in the United States, with significantly greater increases in countries that are more polluted to begin with, according to Schwartz.

Studies indicate that global warming will directly kill hundreds of Americans from exposure to extreme heat during summer months. The U.S. Centers for Disease Control and Prevention have found that extreme heat is responsible for an average of at least 240 deaths a year in the United States. Heat waves can double or triple the overall death rates in large cities. The death toll in the United States from a heat wave during July, 1999, surpassed two hundred people. As many as six hundred people died in Chicago alone during the 1990's due to heat waves. The elderly and very young have been most at risk.

Respiratory illness is only part of the picture. The Sierra Club study indicated that rising heat and humidity would broaden the range of tropical diseases, resulting in increasing illness and death from diseases such as malaria, cholera, and dengue fever, whose range will spread as mosquitoes and other disease vectors migrate.

The effects of El Niño in the 1990's indicate how sensitive diseases can be to changes in climate. A study conducted by Harvard University showed that warming waters in the Pacific Ocean likely contributed to the severe outbreak of cholera that led to thousands of deaths in Latin American countries. Since 1981, the number of cases of dengue fever has risen significantly in South America and has begun to spread into the United States. According to health experts cited by the Sierra Club study, the outbreak of dengue near Texas shows the risks that a warming climate might pose. Epstein and the Sierra Club study concur that if tropical weather expands, tropical diseases will expand.

In many regions of the world, malaria is already resistant to the least expensive, most widely distributed drugs. Worldwide, malaria already causes two million deaths a year, as well as 350 million new infections. The increased incidence of diseases will add to society's expenditures for hospitalization and other health care, the cost of lost productivity, and the trauma of illness and death.

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Exploration and Transportation

Exploration and Historical Trade Routes

The world's exploration was shaped and influenced substantially by economic needs. Lacking certain resources and outlets for trade, many societies built ships, organized caravans, and conducted military expeditions to protect their frontiers and obtain new markets.

Over the last five thousand years, the world evolved from a cluster of isolated communities into a firmly integrated global community and capitalist world system. By the beginning of the twentieth century, explorers had successfully navigated the oceans, seas, and landmasses and gathered many regional economies into the beginnings of a global economy.

Early Trade Systems. Trade and exploration accompanied the rise of civilization in the Middle East. Egyptian pharaohs, looking for timber for shipbuilding, established trade relations with Mediterranean merchants. Phoenicians probed for new markets off the coast of North Africa and built a permanent settlement at Carthage. By 513 B.C.E., the Persian Empire stretched from the Indus River in India to the Libyan coast, and it controlled the pivotal trade routes in Iran and Anatolia. A regional economy was taking shape, linking Africa, Asia, and Europe into a blended economic system.

Alexander the Great's victory against the Persian Empire in 330 B.C.E. thrust Greece into a dominant position in the Middle Eastern economy. Trade between the Mediterranean and the Middle East increased, new roads and harbors were constructed, and merchants expanded into sub-Saharan Africa, Arabia, and India. The Romans later benefited from the Greek foundation. Through military and political conquest, Rome consolidated its control over such diverse areas as Arabia and Britain and built a system of roads and highways that facilitated the growth of an expanding world economy. At the apex of Roman power in 200 C.E., trade routes provided the empire with Greek marble, Egyptian cloth, seafood from Black Sea fisheries, African slaves, and Chinese silk.

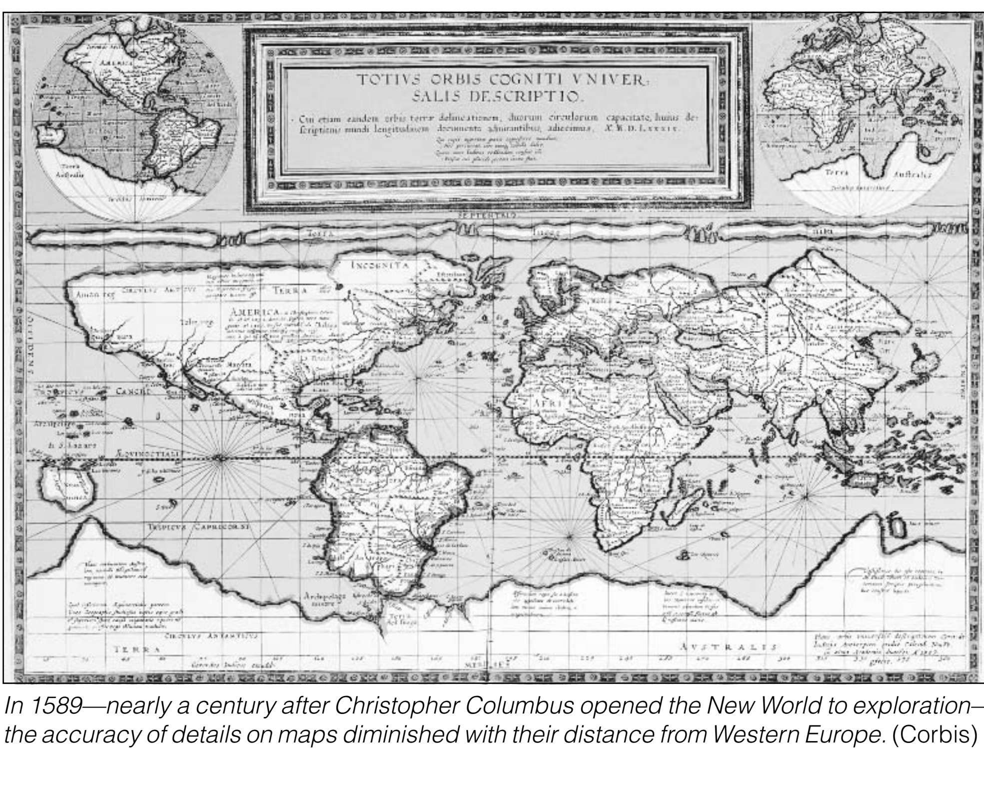
The emergence of a profitable Eurasian trade route linked people, customs, and economies from the South China Sea to the Roman Empire. Although some limited activity occurred during the Hellenistic period, East-West trade flourished following the rise of the Han Dynasty in China. With the opening of the Great Silk Road from 139 B.C.E. to 200 C.E., goods and services were exchanged between people from three different continents.

The Great Silk Road was an intricate network of middlemen stretching from China to the Mediterranean Sea. Eastern merchants sold their products at markets in Afghanistan, Iran, and even Syria, and exchanged a variety of commodities through the use of camel caravans. Chinese spices, perfumes, metals, and especially silk were in high demand. The Parthians from central Asia added their own sprinkling of merchandise, introducing both the East and the West to various exotic fruits, rare birds, and ostrich eggs.

Romans peddled glassware, statuettes, and acrobatic performing slaves. Since communication lines were virtually nonexistent during this period, trade routes were the only means by which ideas regarding art, religion, and culture could mix. The contacts and exchanges enacted along the Great Silk Road initiated a process of cultural diffusion among a diversity of cultures and increased each culture's knowledge of the vast frontiers of world geography.

The Atlantic Slave Trade. Beginning in the fifteenth century, European navigators explored the West African coastline seeking gold. Supplies were difficult to procure, because most of the gold mines were located in the interior along the Senegal River and in the Ashanti forests. Because mining required costly investments in time, labor, and security, the Europeans quickly shifted their focus toward the slave trade. Although slavery had existed since antiquity, the Atlantic slave trade generated one of the most significant movements of people in world history. It led to the forced migration of more than ten million Africans to South America, the Caribbean islands, and North America. It ensured the success of several imperial conquests, and it transformed the demographic, cultural, and political landscape on four continents.

Originally driven by their quest to circumnavigate Africa and open a lucrative trade route with India, the Portuguese initiated a systematic exploration of the West African coastline. The architect of this system, Henry the Navigator, pioneered the use of military force and naval superiority to annex African islands and open up new trade routes, and he increased Portugal's southern frontier with every acquisition. In 1415 his ships captured Ceuta, a prosperous trade center located on the Mediter-



In 1589—nearly a century after Christopher Columbus opened the New World to exploration—the accuracy of details on maps diminished with their distance from Western Europe. (Corbis) ranean coast overlooking North African trade routes. Over the next four decades, Henry laid claim to the Madeira Islands, the Canary Islands, the Azores, and Cape Verde. After his death, other Portuguese explorers continued his pursuit of circumnavigation of Africa.

Diego Cão reached the Congo River in 1483 and sent several excursions up the river before returning to Lisbon. Two explorers completed the Portuguese mission at the end of the fifteenth century. Vasco da Gama, sailing from 1497 to 1499, and Bartholomeu Dias, from 1498 to 1499, who sailed past the southern tip of Africa and eventually reached India. Since Muslims had already created a number of trade links between East Africa, Arabia, and India, Portuguese exploration furthered the integration of various regions into an emerging capitalist world system.

When the Portuguese shifted their trading from gold to slaves, the other European powers followed suit. The Netherlands, Spain, France, and England used their expanding naval technology to explore the Atlantic Ocean and ship millions of slaves across the ocean. A highly efficient and organized trade route quickly materialized. Since the Europeans were unwilling to venture beyond the walls of their coastal fortresses, merchants relied on African sources for slaves, supplying local kings and chiefs with the means to conduct profitable slave-raiding parties in the interior. In both the Congo and the Gold Coast region, many Africans became quite wealthy trading slaves. In 1750 merchants paid the king of Dahomey 250,000 pounds for nine thousand slaves, and his income exceeded the earnings of many in England's merchant and landowning class.

After purchasing slaves, dealers sold them in the Americas to work in the mines or on plantations. Commodities such as coffee and sugar were exported back to Europe for home consumption. Merchants then sold alcohol, tobacco, textiles, and firearms to Africans in exchange for more slaves. This practice was abolished by the end of the nineteenth century, but not before more than ten million Africans had been violently removed from their homeland. The Atlantic slave trade, however, joined port cities from the Gold Coast and Guinea in Africa with Rio de Janeiro, Hispaniola, Havana, Virginia, Charleston, and Liverpool, and constituted a pivotal step toward the rise of a unified global economy.

Magellan and Zheng He. The Portuguese explorer Ferdinand Magellan generated considerable interest in the Asian markets when he led an expedition that sailed around the world from 1519 to 1522. Looking for a quick route to Asia and the Spice Islands, he secured financial backing from the king of Spain. Magellan sailed from Spain in 1519, canvassed the eastern coastline of South America, and visited Argentina. He ultimately traversed the narrow straits along the southern tip of the continent and ventured into the uncharted waters of the Pacific Ocean.

Magellan explored the islands of Guam and the Philippines but was killed in a skirmish on Mactan in 1521. Some of his crew managed to re-

Ferdinand Magellan. (Library of Congress)

turn to Spain in 1522, and one member subsequently published a journal of the expedition that drastically enhanced the world's understanding of the major sea lanes that connected the continents.

China also opened up new avenues of trade and exploration in Southeast Asia during the fifteenth century. Under the direction of Chinese emperor Yongle, explorer Zheng He organized seven overseas trips from 1405 to 1433 and investigated economic opportunities in Korea, Vietnam, the Indian Ocean, and Egypt. His first voyage consisted of more than twenty-eight thousand men and four hundred ships and represented the largest naval force assembled prior to World War I.

Zheng's armada carried porcelains, silks, lacquerware, and artifacts to Malacca, the vital port city in Indonesia. He purchased an Arab medical text on drug therapy and had it translated into Chinese. He introduced giraffes and mahogany wood into the mainland's economy, and his efforts helped spread Chinese ideas, customs, diet, calendars, scales and measures, and music throughout the global economy. Zheng He's discoveries, coupled with all the material gathered by the European explorers, provided cartographers and geographers with a credible store of knowledge concerning world geography.

Emerging Global Trade Networks. From 1400 to 1900, several regional economic systems facilitated the exchange of goods and services throughout a growing world system. Building on the triangular relationships produced by the slave trade, the Atlantic region helped spread new foodstuffs around the globe. Plants and plantation crops provided societies with a plentiful supply of sweet potatoes, squash, beans, and maize. This system, often referred to as the Columbian exchange, also assisted development in other regions by supplying the global economy with an ample money supply in gold and silver. Europeans sent textiles and other manufactures to the Americas. In return, they received minerals from Mexico; sugar and molasses from the Caribbean; money, rum, and tobacco from North America; and foodstuffs from South America. Trade routes also closed the distance between the Pacific coastline in the Americas and the Pacific Rim.

Additional thriving trade routes existed in the African-West Asian region. Linking Europe and Africa with Arabia and India, this area experienced a considerable amount of trade over land and through the sea lanes in the Persian Gulf and Red Sea. Europeans received grains, timber, furs, iron, and hemp from Russia in exchange for wool textiles and silver. Central Asians secured stores of cotton textiles, silk, wheat, rice, and tobacco from India and sold silver, horses, camel, and sheep to the Indians. Ivory, blankets, paper, saltpeter, fruits, dates, incense, coffee, and wine were regularly exchanged among merchants situated along the trade route connecting India, Persia, the Ottoman Empire, and Europe.

Finally, a Russian-Asian-Chinese market provided Russia's ruling czars with arms, sugar, tobacco, and grain, and a sufficient supply of drugs, medicines, livestock, paper money, and silver moved eastward. Overall, this system linked the economies of three continents and guaranteed that a nation could acquire essential foodstuffs, resources, and money from a variety of sources.

Several profitable trade routes existed in the Indian Ocean sector. After Malacca emerged as a key trading port in the sixteenth century, this territory served as an international clearinghouse for the global economy. Indians sent tin, elephants, and wood into Burma and Siam. Rice, silk, and sugar were sold to Bengal. Pepper and other spices were shipped westward across the Arabian Sea, while Ceylon furnished India with vital quantities of jewels, cinnamon, pearls, and elephants. The booming interregional trade routes positioned along the Indian coastline ensured that many of the vast commodities produced in the world system could be obtained in India.

The final region of crucial trade routes was between Southeast Asia and China. While the extent of Asian overseas trade prior to the twentieth century is usually downplayed, an abundance of products flowed across the Bay of Bengal and the South China Sea. Japan procured silver, copper, iron, swords, and sulphur from Cantonese merchants, and Japanese-finished textiles, dyes, tea, lead, and manufactures were in high demand on the mainland. The Chinese also purchased silk and ceramics from the Philippines in exchange for silver. Burma and Siam traded pepper, sappan wood, tin, lead, and saltpeter to China for satin, velvet, thread, and labor. As goods increasingly moved from the Malabar coast in India to the northern boundaries of Korea and Japan, the Pacific Rim played a prominent role in the global economy.

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Road Transportation

Roads—the most common surfaces on which people and vehicles move—are a key part of human and economic geography. Transportation activities form part of a nation's economic product: They strengthen regional economy, influence land and natural resource use, facilitate communication and commerce, expand choices, support industry, aid agriculture, and increase human mobility. The need for roads closely correlates with the relative location of centers of population, commerce, industry, and other transportation.

History of Road Making. The great highway systems of modern civilization have their origin in the remote past. The earliest travel was by foot on paths and trails. Later, pack animals and crude sleds were used. The development of the wheel opened new options. As various ancient civilizations reached a higher level, many of them realized the importance of improved roads.

The most advanced highway system of the ancient world was that of the Romans. When Roman civilization was at its peak, a great system of military roads reached to the limits of the empire. The typical Roman road was bold in conception and construction, built in a straight line

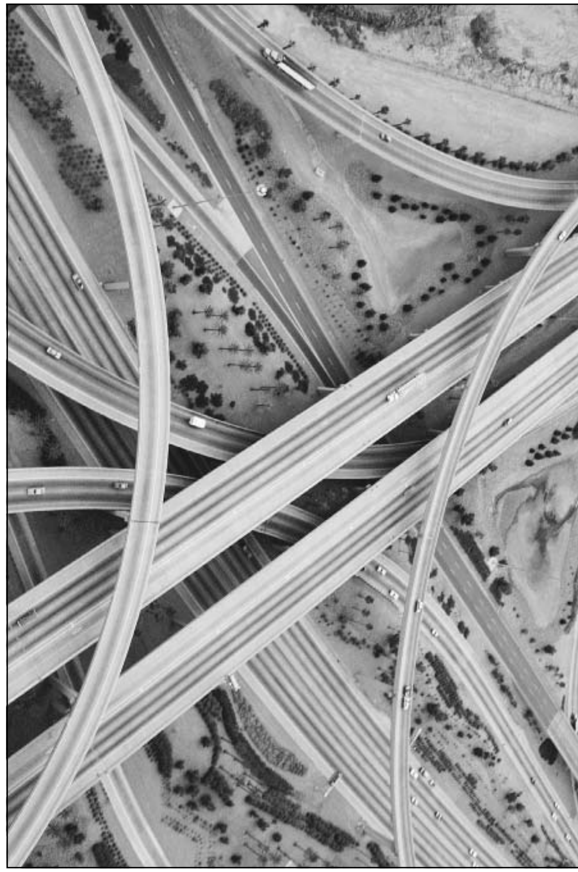
Modern British road built on the bed of an ancient Roman road, whose original siding is still visible. (PhotoDisc)

when possible, with a deep multilayer foundation, perfect for wheeled vehicles.

After the decline of the Roman Empire, rural road building in Europe practically ceased, and roads fell into centuries of disrepair. Commerce traveled by water or on pack trains that could negotiate the badly maintained roads. Eventually, a commercial revival set in, and roads and wheeled vehicles increased.

Interest in the art of road building was revived in Europe in the late eighteenth century. P. Trésaguet, a noted French engineer, developed a new method of lightweight road building. The regime of French dictator Napoleon Bonaparte (1800-1814) encouraged road construction, chiefly for military purposes. At about the same time, two Scottish engineers, Thomas Telford and John McAdam, also developed road-building techniques.

Roads in the United States. Toward the end of the eighteenth century, public demand in the United States led to the improvement of some roads by private enterprise. These improvements generally took the form of toll roads, called "turnpikes" because a pike was rotated in each road to allow entry after the fee was paid, and generally were located in areas ad-



Modern freeway interchange. Passage of the Federal-Aid Highway Act in 1956 was a turning point in the history of highway transportation in the United States. It marked the beginning of the largest peacetime public works program in the history of the world, creating a 41,000-mile National System of Interstate and Defense Highways. (PhotoDisc)

jacent to larger cities. In the early nineteenth century, the federal government paid for an 800-mile-long macadam road from Cumberland, Maryland, to Vandalia, Illinois.

With the development of railroads, interest in road building began to wane. By 1900, however, demand for better roads came from farmers, who wanted to move their agricultural products to market more easily. The bicycle craze of the 1890's and the advent of motorized vehicles also added to the demand for more and better roads. Asphalt and concrete technology was well developed by then; now, the problem was financing. Roads had been primarily a local issue, but the growing demand led to greater state and federal involvement in funding.

The Federal-Aid Highway Act of 1956 was a milestone in the development of highway transportation in the United States; it marked the beginning of the largest peacetime public works program in the history of the world, creating a 41,000-mile National System of Interstate and Defense Highways, built to high standards. Later legislation expanded funding, improved planning, addressed environmental concerns, and provided for more balanced transportation. Other developed countries also developed highway programs but were more restrained in construction.

Roads and Development. Transportation presents a severe challenge for sustainable development. The number of motor vehicles at the beginning of the twenty-first century—estimated at more than 600 million worldwide—is growing almost everywhere at higher rates than either population or the gross domestic product. Overall road traffic grows even more quickly. Americans own the most cars—one for every 1.7 residents—but even in crowded Japan there is one car for every 2.1 people. In Great Britain, there is one car for every 5.3 people.

Highways around the world have been built to help strengthen national unity. The Trans-Canada Highway, the world's longest national road, for example, extends east-west across the breadth of the country. Completed in the 1960's, it had the same goal as the Canadian Pacific Railroad a century before, to improve east-west commerce within Canada.

Sometimes, existing highways need to be upgraded; in less-developed countries, this can simply mean paving a road for all-weather operation. An example of a late-1990's project of this nature was the Brazil-Venezuela Highway project, which had this description: Improve the Brazil-Venezuela highway link by completion of paving along the BR-174, which runs northward from Manaus in the Amazon, through Boa Vista and up to the frontier, so opening a route to the Caribbean. Besides the investment opportunities in building the road itself, the highway would result in investment opportunities in mining, tourism, telecommunications, soy and

Highway Classification

Modern roads can be classified by roadway design or traffic function. The basic type of roadway is the conventional, undivided two-way road. Divided highways have median strips or other physical barriers separating the lanes going in opposite directions.

Another quality of a roadway is its right-of-way control. The least expensive type of system controls most side access and some minor at-grade intersections; the more expensive type has side access fully controlled and no at-grade intersections. The amount of traffic determines the number of lanes. Two or three lanes in each direction is typical, but some roads in Los Angeles have five lanes, while some sections of the Trans-Canada Highway have only one lane. Some highways are paid for entirely from public funds; if users pay directly when they use the road, the roads are called tollways or turnpikes.

Roads are classified as expressway, arterial, collector, and local in urban areas, with a similar hierarchy in rural areas. The highest level—expressway—is intended for long-distance travel.

rice production, trade with Venezuela, manufacturing in the Manaus Free Trade Zone, ecotourism in the Amazon, and energy integration.

Growing road traffic has required increasingly significant national contributions to road construction. Beginning in the 1960's, the World Bank began to finance road construction in several countries. It required that projects be organized to the highest technical and economic standards, with private contracting and international competitive bidding rather than government workers. Still, there were questions as to whether these economic assessments had a road-sector bias and properly incorporated environmental costs. Sustainability was also a question—could the facilities be maintained once they were built?

In the 1990's, the World Bank financed a program to build an asphalt road network in Mozambique. Asphalt makes very smooth roads but is very maintenance-intensive, requiring expensive imported equipment and raw materials. By the end of the decade, the roads required resurfacing but the debt was still outstanding. Alternative materials would have given a rougher road, but it could have been built with local materials and labor.

The European Investment Bank has become a major player in the construction of highways linking Eastern and Western Europe to further European integration. Some of the fastest growth in the world in ownership of autos has been in Eastern Europe. There is a two-way feedback effect between highway construction and auto ownership.

Environment Consequences. Highways and highway vehicles have social, economic, and environmental consequences. Compromise is often necessary to balance transportation needs against these constraints. For example, in Israel, there has been a debate over construction of the Trans-Israel highway, a $1.2 billon, six-lane highway stretching 180 miles (300 km.) from Galilee to the Negev.

Demand on resources for worldwide road infrastructure far exceeds available funds; governments increasingly are looking to external sources such as tolls. Private toll roads, common in the nineteenth century, are making a comeback. This has spread from the United States to Europe, where private and government-owned highway operators have begun to sell shares on the stock market. Private companies are not only operating and financing roads in Europe, they are also designing and building them. In Eastern Europe, where road construction languished under communism, private financing and toll collecting are seen as the means of supporting badly needed construction.

Industrial development in poor countries is adversely affected by limited transportation. Costs are high—unreliable delivery schedules make it necessary to maintain excessive inventories of raw materials and finished goods. Poor transport limits the radius of trade and makes it difficult for manufacturers to realize the economies of large-scale operations to compete internationally.

In more difficult terrain, roads become more expensive because of a need for cuts and fills, bridges, and tunnels. To save money, such roads often have steeper grades, sharper curves, and reduced width than might be desired. Severe weather changes also damage roads, further increasing maintenance costs.

Stephen B. Dobrow

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Information on road transportation can be found at the Web sites of professional organizations involved in highways, such as the Institute of Transportation Engineers (www.ite.org)and the American Association of State Highway and Transportation Officials (www.aashto.org).

The Institute for Transportation and Development Policy is an organization concerned with worldwide sustainable transportation; its Web site features information on programs and publications and links to relevant sites. (www.itdp.org)

Railroads

Railroads were the first successful attempts by early industrial societies to develop integrated communication systems. At the start of the twenty-first century, global societies are linked by Internet systems dependent upon communication satellites orbiting around Earth. The speed by which information and ideas can reach remote places breaks down isolation and aids in the developing of a world community. In the nineteenth century, railroads had a similar impact. Railroads were critical for the creation of an urban-industrial society: They linked regions and remote places together, were important contributors in developing nation-states, and revolutionized the way business was conducted through the creation of corporations. Although alternative forms of transportation exist at the beginning of the twenty-first century, railroads remain important.

The Industrial Revolution and the Railroad. Development of the steam engine gave birth to the railroad. Late in the eighteenth century, James Watt perfected his steam engine in England. Water was superheated by a boiler and vaporized into steam, which was confined to a cylinder behind a piston. Pressure from expanding steam pushes the cylinder forward, causing it to do work if it is attached to wheels. Watt's engine was used in the manufacturing of textiles, thus beginning the Industrial Revolution whereby machine technology mass produced goods for mass consumption. Robert Fulton was the first innovator to commercially apply the steam engine to water transportation. His steamboat *Clermont* made its maiden voyage up the Hudson River in 1807.

Not until the 1820's was a steam engine used for land transportation. Rivers and lakes were natural features where no road needed to be built. Applying steam to land movement required some type of roadbed. In England, George Stephenson ran a locomotive over iron strips attached to wooden rails. Within a short time, England's forges were able to roll rails made completely of iron shaped like an inverted "U."

How much profit a manufacturer could make was determined partially by the cost of transportation. The lower the cost of moving cargo and people, the higher the profitability. Several alternatives existed before the emergence of railroads. Toll roads were too slow. A loaded

Washington, D.C., one of the last major world capitals to build a subway system, finally opened its own subway in 1976. Drawing on lessons learned in other systems, it built one of the most attractive and efficient systems in the world. (PhotoDisc) wagon pulled by four horses could average 15 miles (25 km.) a day.

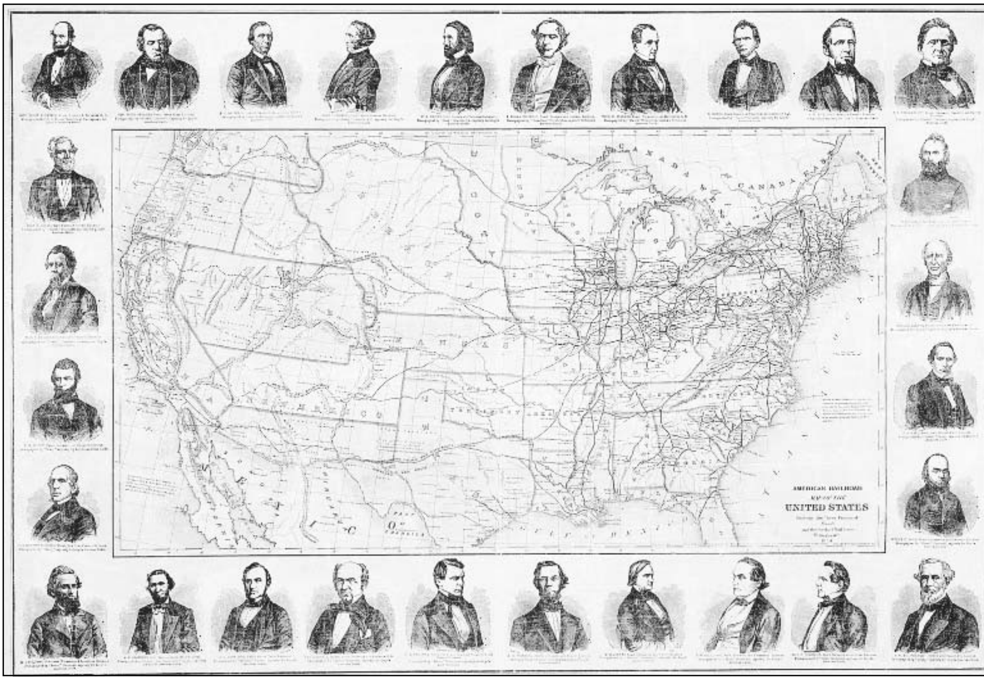
Canals were more efficient than early railroads, because barges pulled by mules moved faster over waterways. However, canals could not be built everywhere, especially over mountains. The application of railroad technology, using steam as a power source, made it possible to overcome obstacles in moving goods and people over considerable distances and at profitable costs. Railroads transformed the way goods were purchased by reducing the costs for consumers, thus raising the living standards in industrial societies. Railroads transformed the human landscape by strengthening the link between farm and city, changed commercial cities into industrial centers, and started early forms of suburban growth well before automobiles arrived.

Financing Railroads. Constructing railroads was costly. Tunnels had to be blasted through mountains, and rivers had to be crossed by bridges. Early in the building of U.S. railroads, the nation's iron foundries could not meet the demands for rolled rails. Rails had to be imported from England until local forges developed more efficient technologies. Once a railroad was completed, there was a constant need to maintain the right-of-way so that traffic flow would not be disrupted. Accidents were frequent, and it was an early practice to burn damaged cars because salvaging them was too expensive.

In some countries, railroads were built and operated by national governments. In the United States, railroads were privately owned; however, it was impossible for any single individual to finance and operate a rail system with miles of track. Businessmen raised money by selling stocks and bonds. Just as investors buy stocks in modern high-technology companies, investors purchased stocks and bonds in railroads.

Investing in railroads was good as long as they earned profits and returned money to their investors, but not all railroads made sufficient profits to reward their investors. Competition among railroads was heavy in the United States, and some railroads charged artificially low fares to attract as much business as they could. When ambitious investment schemes collapsed, railroads went bankrupt and were taken over by financiers.

Selling shares of common stock and bonds was made possible by creating corporations. Railroads were granted permission from state governments to organize a corporation. Every investor owned a portion of the railroad. Stockholders' interests were served by boards of directors, and all business transactions were opened for public inspection. One important factor of the corporation was that it relieved individuals of the responsibilities associated with accidents. The railroad, as a corporation, was held accountable, and any compensation for claims made against the company came out of corporate funds, not from individual pockets. This had an impact on the law profession, as law schools began specializing in legal matters relevant to railroads and interstate commerce.



Contemporary map of the United States showing three different proposed routes for the first transcontinental railroad. (Corbis)

The Success of Railroads. Railroads usually began by radiating outward from port cities where merchants engaged in transoceanic trade. A classic example, in the United States, is the country's first regional railroad—the Baltimore and Ohio. Construction commenced from Baltimore in 1828; by 1850, the railroad had crossed the Appalachian Mountains and was on the Ohio River at Wheeling, Virginia.

Once trunk lines were established, rail networks became more intensive as branch lines were built to link smaller cities and towns. Countries with extremely large continental dimensions developed interior articulating cities where railroads from all directions converged. Chicago and Atlanta are two such cities in the United States. Chicago was surrounded by three circular railroads (belts) whose only function was to interchange cars. Railroads from the Pacific Coast converged with lines from the Atlantic Coast as well as routes moving north from the Gulf Coast.

Mechanized farms and heavy industries developed within the network. Railroads made possible the extraction of fossil fuels and metallic ores, the necessary ingredients for industrial growth. Extension of railroads deep into Eastern Europe helped to generate massive waves of immigration into both North and South America, creating multicultural societies.

Building railroads in Africa and South Asia made it possible for Europe to increase its political control over native populations. The ultimate aim of the colonial railroad was to develop a colony's economy according to the needs of the mother country. Railroads were usually single-line routes transhipping commodities from interior centers to coastal ports for exportation. Nairobi, Kenya, began as a rail hub linking British interests in Uganda with Kenya's port city of Mombasa. Similar examples existed in Malaysia and Indonesia.

Railroads generated conflicts among colonial powers as nations attempted to acquire strategic resources. In 1904-1905 Russia and Japan fought a war in the Chinese province of Manchuria over railroad rights; Imperial Germany attempted to get around British interests in the Middle East by building a railroad linking Berlin with Baghdad to give Germany access to lucrative oil fields. India was a region of loosely connected provinces until British railroads helped establish unification. The resulting sense of national unity led to the termination of British rule in 1947 and independence for India and Pakistan.

In the United States, private railroads discontinued passenger service among cities early in the 1970's and the responsibility was assumed by the federal government (Amtrak). Most Americans riding trains do so as commuters traveling from the suburbs to jobs in the city. High-speed train service is planned along the rail corridor between Washington and New York, Amtrak's most popular route. Passenger service remains popular in Japan and Europe. France, Germany, and Japan operate high-speed luxury trains with speeds averaging above 100 miles (160 km.) per hour.

Japanese bullet trains, which move commuters in and out of major cities at speeds well in excess of one hundred miles per hour. (Corbis)

Railroads are no longer the exclusive means of mechanized land transportation as they were early in the twentieth century. Although competition from motor vehicles and air freight provide alternate choices, railroads have remained important. France and England have direct rail linkage beneath the English Channel. In the United States, great railroad mergers and the application of computer technology have reduced operating costs while increasing profits. Transoceanic container traffic has been aided by railroads hauling trailers on flatcars. Railroads began the process of bringing regions within a nation together in the nineteenth century just as the computer and the World Wide Web began uniting nations throughout the world at the end of the twentieth century.

Sherman E. Silverman

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The World Rail and Transit site lists different types of worldwide railroad transit systems by both country and city, with definitions and source materials. (home.cc.umanitoba.ca/~wyatt/rail-transit-list.html)

Air Transportation

The movement of goods and people among places is an important field of geographic study. Transportation routes form part of an intricate global network through which commodities flow. Speed and cost determine the nature and volume of the materials transported, so air trans-

A national memorial to the Wright brothers on Maryland's Outer Banks commemorates the site of their first heavier-than-air flight. (PhotoDisc)

portation has both advantages and disadvantages when compared with road, rail, or water transport.

Early Flying Machines. The transport of people and freight by air is less than a century old. Although hot-air balloons were used in the late eighteenth century for military purposes, aerial mapping, and even early photography, they were never commercially important as a means of transportation. In the late nineteenth century, the German count Ferdinand von Zeppelin began experimenting with dirigibles, which added self-propulsion to lighter-than-air craft. These aircraft were used for military purposes, such as the bombing of Paris in World War I. However, by the 1920's zeppelins had become a successful means of passenger transportation. They carried thousands of passengers on trips in Europe or across the Atlantic Ocean and also were used for exploration. Nevertheless, they had major problems and were soon superseded by flying machines heavier than air. The early term for such a machine was "aeroplane," which is still the word used for airplane in Great Britain.

Following pioneering advances with the internal combustion engine and in aerodynamic theory using gliders, the development of powered flight in a heavier-than-air machine was achieved by Wilbur and Orville Wright in December, 1903. From that time, the United States moved to the forefront of aviation, with Great Britain and Germany also making significant contributions to air transport. World War I saw the further development of aviation for military purposes, evidenced by the infamous bombing of Guernica.

Early Commercial Service. Two decades after the Wright brothers' brief flight, the world's first commercial air service began, covering the short distance from Tampa to St. Petersburg in Florida. The introduction of airmail service by the U.S. Post Office provided a new, regular source of income for commercial airlines in the United States, and from these beginnings arose the modern Boeing Company, United Airlines, and American Airlines. Europe, however, was the home of the world's first commercial airlines. These include the Deutsche Luftreederie in Germany, which connected Berlin, Leipzig, and Weimar in 1919; Farman in France, which flew from Paris to London; and KLM in the Netherlands (Amsterdam to London), followed by Qantas—the Queensland and Northern Territory Aerial Services, Limited—in Australia. The last two are the world's oldest still operating airlines.

Aircraft played a vital role in World War II, as a means of attacking enemy territory, defending territory, and transporting people and equipment. A humanitarian use of air power was the Berlin Air Lift of 1948, when Western nations used airplanes to deliver food and medical supplies to the people of West Berlin, which the Soviet Union briefly blockaded on the ground.

Cargo and Passenger Service. The jet engine was developed and used for fighter aircraft during World War II by the Germans, the British, and the United States. Further research led to civil jet transport, and by the 1970's, jet planes accounted for most of the world's air transportation. Air travel in the early days was extremely expensive, but technological advances enabled longer flights with heavier loads, so commercial air travel became both faster and more economical.

Although people in the United States still use personal vehicles for most of their travel, they prefer air travel for longer trips. Almost three-quarters of trips in excess of 1,000 miles (1,600 km.) that Americans undertook during the 1990's were made by airplane. Most air travel is made for business purposes. The United States had more than 1,500 airports in the year 2000, but more than half of these were short, privately owned, unpaved airstrips. There are 180 commercial or military airports with runways more than 9,800 feet (3,000 meters) long.

Between 1960 and 2000 the number of passengers carried by air grew at an annual rate of 9 percent. Air travel is also extremely safe. In 1999 there were 674 airline fatalities, which is only 0.36 percent of the number of passengers. At the same time, the volume of freight increased by 7 percent and the volume of mail by 11 percent. Some 30 percent of the world's trade, by value, is carried by air. In 1999 more than 1,337 million passengers were carried on scheduled domestic or international flights.

More than seven thousand airplanes fly for airlines around the world on any given day, logging almost 5 billion miles (8 billion km.) each year.

North Americans dominate the world in use of commercial flights, accounting for almost 40 percent of all passenger miles flown. In the year 2000 almost half of all air passengers boarded flights in America. In 1999 Delta Airlines carried the greatest number of passengers in the world—105.5 million passengers on its domestic and international routes. British Airways and Lufthansa were the major international carriers, with 30.3 and 27.3 million international passengers respectively. Seven of the top ten of the world's major domestic airlines were U.S. carriers, with the other three being Japanese.

The biggest air cargo carriers in 1999 were Federal Express, which carried more than 5 million tons of cargo, and United Parcel Service (3 million tons). For international air freight, the leaders in 1999 were Federal Express (1.25 million tons), Lufthansa (1.1 million tons), and Korean Air (0.9 tons). Federal Express and UPS also led in domestic air freight transport.

The first commercial supersonic airliner, the British-French Concorde, which could fly at more than twice the speed of sound, began regular service in early 1976. However, the fleet was grounded after a Concorde crash in France in mid-2000. The first space shuttle flew in 1981, and the hundredth space shuttle launch took place in October, 2000. The shuttles have transported 600 people and 3 million pounds (1.36 million kilograms) of cargo into space.

Jet planes only slowly entered the commercial airline business after the mid-1950's, but by the 1970's jets accounted for the majority of passenger miles in the air. (PhotoDisc)

Health Problems Transported by Air. The high speed of intercontinental air travel and the increasing numbers of air travelers have increased the risk of exotic diseases being carried into destination countries, thereby globalizing diseases previously restricted to certain parts of the world. Passengers traveling by air might be unaware that they are carrying infections or viruses. The worldwide spread of HIV/AIDS after the 1980's was accelerated by international air travel.

Disease vectors such as flies or mosquitoes can also make air journeys unnoticed inside airplanes. At some airports, both airplane interiors and passengers are subjected to spraying with insecticide upon arrival and before deplaning. The West Nile virus (West Nile encephalitis) was previously found only in Africa, Eastern Europe, and West Asia, but in the 1990's it appeared in the northeastern United States, transported there by birds, mosquitos, or people.

It was feared in the mid-1990's that the highly infectious and deadly Ebola virus, which originated in tropical Africa, might spread to Europe and the United States, by air passengers or through the importing of monkeys. The devastation of native bird communities on the island of Guam has been traced to the emergence there of a large population of brown tree snakes, whose ancestors are thought to have arrived as accidental stowaways on a military airplane in the late 1940's.

In 2003, a previously unknown virus called severe acute respiratory syndrome, or SARS, emerged and caused an international alarm in the air transportation industry because it was believed to be carried by air passengers. The virus first appeared in southern China and spread rapidly to other Asian countries, then to Canada and other Western Countries.

Ray Sumner

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Economic Geography

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Agriculture

Traditional Agriculture

Two agricultural practices that are widespread among the world's traditional cultures, slash-and-burn and nomadism, share several common features. Both are ancient forms of agriculture, both involve farmers not remaining in a fixed location, and both can pose serious environmental threats if practiced in a nonsustainable fashion. The most significant difference between the two forms is that slash-and-burn generally is associated with raising field crops, while nomadism as a rule involves herding livestock.

Slash-and-Burn Agriculture. Farmers have practiced slash-and-burn agriculture, which is also referrred to as shifting cultivation or swidden agriculture, in almost every region of the world where the climate makes farming possible. Although at the end of the twentieth century slash-and-burn agriculture was most commonly found in tropical areas such as the Amazon River basin in South America, swidden agriculture also once dominated agriculture in more temperate regions, such as northern Europe. Swidden agriculture was, in fact, common in Finland and northern Russia well into the early decades of the twentieth century.

Slash-and-burn acquired its name from the practice of farmers who cleared land for planting crops by cutting down the trees or brush on the land and then burning the fallen timber on the site. The farmers literally slash and burn. The ashes of the burnt wood add minerals to the soil, which temporarily improves its fertility. Crops the first year following clearing and burning are generally the best crops the site will provide. Each year after that, the yield diminishes slightly as the fertility of the soil is depleted.

Farmers who practice swidden cultivation do not attempt to improve fertility by adding fertilizers such as animal manures but instead rely on the soil to replenish itself over time. When the yield from one site drops below acceptable levels, the farmers then clear another piece of land, burn the brush and other vegetation, and cultivate that site while leaving their previous field to lie fallow and its natural vegetation to return. This cycle will be repeated over and over, with some sites being allowed to lie fallow indefinitely while others may be revisited and farmed again in five, ten, or twenty years.

Farmers who practice shifting cultivation do not necessarily move their dwelling places as they change the fields they cultivate. In some geographic regions, farmers live in a central village and farm cooperatively, with the fields being alternately allowed to remain fallow, and the fields being farmed making a gradual circuit around the central village. In

Slash-and-burn agriculture takes its name from the practice of clearing land for planting by cutting down the trees and brush and burning the fallen materials to fertilize the soil with the ashes of the burned materials.

other cases, the village itself may move as new fields are cultivated. Anthropologists studying indigenous peoples in Amazonia, for example, discovered that village garden sites were on a hundred-year cycle. Villagers farmed cooperatively, with the entire village working together to clear a garden site. That garden would be used for about five years, then a new site was cleared. When the garden moved an inconvenient distance from the village, about once every twenty years, the entire village would move to be closer to the new garden. Over a period of approximately one hundred years, a village would make a circle through the forest, eventually ending up close to where it had been located long before any of the present villagers had been born.

In more temperate climates, individual farmers often owned and lived on the land on which they practiced swidden agriculture. Farmers in Finland, for example, would clear a portion of their land, burn the brush and other covering vegetation, grow grains for several years, and then allow that land to remain fallow for from five to twenty years. The individual farmer rotated cultivation around the land in a fashion similar to that practiced by whole villages in other areas, but did so as an individual rather than as part of a communal society.

Although slash-and-burn is frequently denounced as a cause of environmental degradation in tropical areas, the problem with shifting cultivation is not the practice itself but the length of the cycle. If the cycle of shifting cultivation is long enough, forests will grow back, the soil will regain its fertility, and minimal adverse effects will occur. In some regions, a piece of land may require as little as five years to regain its maximum fertility; in others, it may take one hundred years. Problems arise when growing populations put pressure on traditional farmers to return to fallow land too soon. Crops are smaller than needed, leading to a vicious cycle in which the next strip of land is also farmed too soon, and each site yields less and less. As a result, more and more land must be cleared.

Nomadism. Nomadic peoples have no permanent homes. They earn their livings by raising herd animals, such as sheep, cattle, or horses, and they spend their lives following their herds from pasture to pasture with the seasons. Most nomadic animals tend to be hardy breeds of goats, sheep, or cattle that can withstand hardship and live on marginal lands. Traditional nomads rely on natural pasturage to support their herds and grow no grains or hay for themselves. If a drought occurs or a traditional pasturing site is unavailable, they can lose most of their herds to starvation.

In many nomadic societies, the herd animal is almost the entire basis for sustaining the people. The animals are slaughtered for food, clothing is woven from the fibers of their hair, and cheese and yogurt may be made from milk. The animals may also be used for sustenance without being slaughtered. Nomads in Mongolia, for example, occasionally drink horses' blood, removing only a cup or two at a time from the animal. Nomads go where there is sufficient vegetation to feed their animals.

In mountainous regions, nomads often spend the summers high up on mountain meadows, returning to lower altitudes in the autumn when snow begins to fall. In desert regions, they move from oasis to oasis, going to the places where sufficient natural water exists to allow brush and grass to grow, allowing their animals to graze for a few days, weeks, or months, then moving on. In some cases, the pressure to move on comes not from the depletion of food for the animals but from the depletion of a water source, such as a spring or well. At many natural desert oases, a natural water seep or spring provides only enough water to support a nomadic group for a few days at a time.

In addition to true nomads—people who never live in one place permanently—a number of cultures have practiced seminomadic farming: The temperate months of the year, spring through fall, are spent following the herds on a long loop, sometimes hundreds of miles long, through traditional grazing areas, then the winter is spent in a permanent village.

Nomadism has been practiced for millennia, but there is strong pressure from several sources to eliminate it. Pressures generated by industrialized society are increasingly threatening the traditional cultures of nomadic societies, such as the Bedouin of the Arabian Peninsula. Traditional grazing areas are being fenced off or developed for other purposes. Environmentalists are also concerned about the ecological damage caused by nomadism.

Nomads generally measure their wealth by the number of animals they own and so will try to develop their herds to be as large as possible, well beyond the numbers required for simple sustainability. The herd animals eat increasingly large amounts of vegetation, which then has no opportunity to regenerate, and desertification may occur. Nomadism based on herding goats and sheep, for example, has been blamed for the expansion of the Sahara Desert in Africa. For this reason, many environmental policymakers have been attempting to persuade nomads to give up their roaming lifestyle and become sedentary farmers.

Nancy Farm Männikkö

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Commercial Agriculture

Commercial farmers are those who sell substantial portions of their output of crops, livestock, and dairy products for cash. In some regions, commercial agriculture is as old as recorded history, but only in the twentieth century did the majority of farmers come to participate in it. For individual farmers, this has offered the prospect of larger income and the opportunity to buy a wider range of products. For society, commercial agriculture has been associated with specialization and increased productivity. Commercial agriculture has enabled world food production to increase more rapidly than world population, improving nutrition levels for millions of people.

Tokyo market (Corbis)

Steps in Commercial Agriculture. In order for commercial agriculture to exist, products must move from farmer to ultimate consumer, usually through six stages:

1. Processing, packaging, and preserving to protect the products and reduce their bulk to facilitate shipping.
2. Transport to specialized processing facilities and to final consumers.
3. Networks of merchant middlemen who buy products in bulk from farmers and processors and sell them to final consumers.
4. Specialized suppliers of inputs to farmers, such as seed, livestock feed, chemical inputs (fertilizers, insecticides, pesticides, soil conditioners), and equipment.
5. A market for land, so that farmers can buy or lease the land they need.
6. Specialized financial services, especially loans to enable farmers to buy land and other inputs before they receive sales revenues.

Improvements in agricultural science and technology have resulted from extensive research programs by government, business firms, and universities.

International Trade. Products such as grain, olive oil, and wine moved by ship across the Mediterranean Sea in ancient times. Trade in spices, tea, coffee, and cocoa provided powerful stimulus for exploration and colonization around 1500 C.E. The coming of steam locomotives and

The romance of cowboys riding the range and driving cattle to market has become largely a thing of the past, as modern methods of livestock management have evolved. (PhotoDisc)

steamships in the nineteenth century greatly aided in the shipment of farm products and spurred the spread of population into potentially productive farmland all over the world. Beginning with Great Britain in the 1840's, countries were willing to relinquish agricultural self-sufficiency to obtain cheap imported food, paid for by exporting manufactured goods.

Most of the leaders in agricultural trade were highly developed countries, which typically had large amounts of both imports and exports. These countries are highly productive both in agriculture and in other commercial activities. Much of their trade is in high-value packaged and processed goods. Although the vast majority of China's labor force works in agriculture, their average productivity is low and the country showed an import surplus in agricultural products. The same was true for Russia. India, similar to China in size, development, and population, had relatively little agricultural trade. Australia and Argentina are examples of countries with large export surpluses, while Japan and South Korea had large import surpluses. Judged by volume, trade is dominated by grains, sugar, and soybeans. In contrast, meat, tobacco, cotton, and coffee reflect much higher values per unit of weight.

The United States. Blessed with advantageous soil, topography, and climate, the United States has become one of the most productive agricultural countries in the world. Technological advances have enabled the

United States to feed its own residents and export substantial quantities with only 2 percent of its labor force engaged directly in farming. In the 1990's there were about two million farms cultivating about one billion acres. They produced about $200 billion worth of products. After expenses, this yielded about $50 billion of net farm income—an average of only about $25,000 per farm. However, most farm families derive substantial income from nonfarm employment.

There is a great deal of agricultural specialization by region. Corn, soybeans, and wheat are grown in many parts of the United States (outside New England). Some other crops have much more limited growing areas. Cotton, rice, and sugarcane require warmer temperatures. Significant production of cotton occurred in seventeen states, rice in six, and sugarcane in four. Twelve states were leaders in agriculture in 1998: Iowa in corn, soybeans, and hogs; Illinois in corn and soybeans; Texas and Nebraska in cattle; California in fruits, vegetables, and dairy products; Florida in fruits and vegetables; Wisconsin in dairy products; Georgia and Arkansas in broiler chickens; North Carolina in hogs; and North Dakota and Kansas in wheat. Typically the top two states in a category account for about 30 percent of sales. Fruits and vegetables are the main exception; the great size, diversity, and mild climate of California gives it a dominant 45 percent.

Farmland in Iowa, which like other regions has its own specializations. (PhotoDisc)

Socialist Experiments. Under the dictatorship of Joseph Stalin, the communist government of the Soviet Union established a program of compulsory collectivized agriculture in 1929. Private ownership of land, buildings, and other assets was abolished. There were some state farms, "factories in the fields," operated on a large scale with many hired workers. Most, however, were collective farms, theoretically run as cooperative ventures of all residents of a village, but in practice directed by government functionaries. The arrangements had disastrous effects on productivity and kept the rural residents in poverty. Nevertheless, similar arrangements were established in China in 1950 under the rule of Mao Zedong. A restoration of commercial agriculture after Mao's death in 1976 enabled China to achieve greater farm output and farm incomes.

Most Western countries, including the United States, subsidize agriculture and restrict imports of competing farm products. Objectives are to support farm incomes, reduce rural discontent, and slow the downward trend in the number of farmers. In 1998 the European Union spent nearly $150 billion in farm support, and Japan spent $50 billion. Restricting imports kept prices high for consumers. Such policies led to bitter disputes with the United States, which wanted to open world markets for U.S. farm exports.

Problems for Farmers. Farmers in a system of commercial agriculture are vulnerable to changes in market prices as well as the universal problems of fluctuating weather. Congress tried to reduce farm subsidies through the Freedom to Farm Act of 1996, but serious price declines in 1997-1999 led to backtracking. Efforts to increase productivity by genetic alterations, radiation, and feeding synthetic hormones to livestock have drawn critical responses from some consumer groups. Environmentalists have been concerned about soil depletion and water pollution resulting from chemical inputs.

The Heritage Seed Movement

Modern hybrid seeds have increased yields and enabled the tremendous productivity of the modern mechanized farm. However, the widespread use of a few hybrid varieties has meant that almost all plants of a given species in a wide area are almost identical genetically. This loss of biodiversity, or the range of genetic difference in a given species, means that a blight could wipe out an entire season's crop. Historical examples of blight include the nineteenth century Great Potato Famine of Ireland and the 1971 corn blight in the United States.

In response to the concern for biodiversity, there has been a movement in North America to preserve older forms of crops with different genes that would otherwise be lost to the gene pool. Nostalgia also motivates many people to keep alive the varieties of fruits and vegetables that their grandparents raised. Many older recipes do not taste the same with modern varieties of vegetables that have been optimized for commercial considerations such as transportability. Thus, raising heritage varieties also can be a way of continuing to enjoy the foods one's ancestors ate.

Productivity and World Hunger. Despite advances in agricultural production, the problem of world hunger persists. Even in countries that store surpluses of farm commodities, there are still people who go hungry. In less-developed countries, the prices of imported food from the West are too low for local producers to compete and too high for the poor to buy them.

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Modern Agricultural Problems

Ever since human societies started to grow their own food, there have been problems to solve. Much of the work of nature was disrupted by the work of agriculture as many as ten thousand years ago. Nature took care of the land and made it productive in its own intricate way, through its own web of interdependent systems. Agriculture disrupts those systems with the hope of making the land even more productive, growing even more food to feed even more people. Since the first spade of soil was turned over and the first plants domesticated, farmers have been trying to discover how to care for the land as well as nature did before.

Many modern problems in agriculture are not really modern at all. Erosion and pollution, for example, have been around as long as agriculture. However, agriculture has changed drastically within those ten thousand years, especially since the dawn of the Industrial Revolution in the seventeenth century. Erosion and pollution are now bigger problems than before and have been joined by a host of others that are equally critical—not all related to physical deterioration. Modern farmers use many more machines than did farmers of old, and modern machines require advanced sources of energy to unleash their power. The machines do more work than could be accomplished before, so fewer farmers are needed, which causes economic problems.

Cities continue to grow bigger as land—usually the best farmland around—is converted to homes and parking lots for shopping centers. The farmers that remain on the land, needing to grow ever more food, turn to the research and engineering industries to improve their seeds. These industries have responded with recombinant technologies that move genes from one species to another; for example, genes cut from peanuts may be spliced into chickens. This creates another set of cultural problems, which are even more difficult to solve because most are still "potential"—their impact is not yet known.

Erosion. Soil loss from erosion continues to be a huge problem all over the world. As agriculture struggles to feed more millions of people, more land is plowed. The newly plowed lands usually are considered more marginal, meaning they are either too steep, too thin, or too sandy; are subject to too much rain; or suffer some other deficiency. Natural vegetative cover blankets these soils and protects them from whatever erosive agents are active in their regions: water, wind, ice, or gravity. Plant cover also increases the amount of rain that seeps downward into the soil rather than running off into rivers. The more marginal land that is turned over for crops, the faster the erosive agents will act and the more erosion will occur.

Expansion of land under cultivation is not the only factor contributing to erosion. Fragile grasslands in dry areas also are being used more intensively. Grazing more livestock than these pastures can handle decreases the amount of grass in the pasture and exposes more of the soil to wind—the primary erosive agent in dry regions.

Overgrazing can affect pastureland in tropical regions too. Thousands of acres of tropical forest have been cleared to establish cattle-grazing ranges in Latin America. Tropical soils, although thick, are not very fertile. Fertility comes from organic waste in the surface layers of the soil. Tropical soils form under constantly high temperatures and receive much more rain than soils in moderate, midlatitude climates; thus, tropical organic waste materials rot so fast they are not worked into the soil at all. After one or two growing seasons, crops grown in these soils will yield substantially less than before.

Tropical fields require fallow periods of about ten years to restore themselves after they are depleted. That is why tropical cultures using slash-and-burn methods of agriculture move to new fields every other year in a cycle that returns them to the same place about every ten years, or however long it takes those particular lands to regenerate. The heavy forest cover protects these soils from exposure to the massive amounts of rainfall and provides enough organic material for crops—as long as the forest remains in place. When the forest is cleared, however, the resulting grassland cannot provide the adequate protection, and erosion accelerates. Grasslands that are heavily grazed provide even less protection from heavy rains, and erosion accelerates even more.

The use of machines also promotes erosion, and modern agriculture relies on machinery: tractors, harvesters, trucks, balers, ditchers, and so on. In the United States, Canada, Europe, Russia, Brazil, South Africa, and other industrialized areas, machinery use is intense. Machinery use is also on the rise in countries such as India, China, Mexico, and Indonesia, where traditional nonmechanized methods are practiced widely. Farming machines, in gaining traction, loosen the topsoil and inhibit vegetative cover growth, especially when they pull behind them any of the various farm implements designed to rid the soil of weeds, that is, all vegetation except the desired crop. This leaves the soil more exposed to erosive weather, so more soil is carried away in the runoff of water to streams.

Eco-fallow farming has become more popular in the United States and Europe as a solution to reducing erosion. This method of agriculture, which leaves the crop residue in place over the fallow (nongrowing) sea-

Desertification

Desertification is the extension of desert conditions into new areas. Typically, this term refers to the expansion of deserts into adjacent nondesert areas, but it can also refer to the creation of a new desert. Land that is susceptible to prolonged drought is always in danger of losing its vegetative ground cover, thereby exposing its soil to wind. The wind carries away the smaller silt particles and leaves behind the larger sand particles, stripping the land of its fertility. This naturally occurring process is assisted in many areas by overgrazing.

In the African Sahel, south of the Sahara, the impact of desertification is acute. Recurring drought has reduced the vegetation available for cattle, but the need for cattle remains high to feed populations that continue to grow. The cattle eat the grass, the soil is exposed, and the area becomes less fertile and less able to support the population. The desert slowly encroaches, and the people must either move or die.

son, does not root the soil in place, however. Dead plants do not "grab" the soil like live plants that need to extract from it the nutrients they need to live. So erosion continues, even though it is at a slower rate. Eco-fallow methods also require heavier use of chemicals, such as herbicides, to "burn down" weed growth at the start of the growing season, which contributes to accelerated erosion and increases pollution.

Pollution. Pollution, besides being a problem in general, continues to grow as an agricultural problem. With the onset of the Green Revolution, the use of herbicides, insecticides, and pesticides has increased dramatically all over the world. These chemicals are not used completely in the growth of the crop, so the leftovers (residue) wash into, and contaminate, surface and groundwater supplies. These supplies then must be treated to become useful for other purposes, a job nature used to do on its own. Agricultural chemicals reduce nature's ability to act as a filter by inhibiting the growth of the kinds of plant life that perform that function in aquatic environments. The chemical residues that are not washed into surface supplies contaminate wells.

As chemical use increases, contamination accumulates in the soil and fertility decreases. The microorganisms and animal life in the soil, which had facilitated the breakdown of soil minerals into usable plant products, are no longer nourished because the crop residue on which they feed is depleted, or they are killed by the active ingredients in the chemical. As a result, soil fertility must be restored to maintain yield. Chemical replacement is usually the method of choice, and increased applications of chemical fertilizers intensify the toxicity of this cyclical chemical dependency.

Chemicals, although problematic, are not as difficult to contend with as the increasingly heavy silt load choking the life out of streams and rivers. Accelerated erosion from water runoff carries silt particles into streams, where they remain suspended and inhibit the growth of many beneficial forms of plant and animal life. The silt load in U.S. streams has become so heavy that the Mississippi River delta is growing faster than it used to. The heavy silt load, combined with the increased load of chemical residues, is seriously taxing the capabilities of the ecosystems around the delta that filter out sediments, absorb nutrients, and stabilize salinity levels for ocean life, creating an expanding dead zone.

This general phenomenon is not limited to the Mississippi delta—it is widespread. Its impact on people is high, because most of the world's population lives in coastal zones and comes in direct contact with the sea. Additionally, eighty percent of the world's fish catch comes from the coastal waters over continental shelves that are most susceptible to this form of pollution.

Monoculture. Modern agriculture emphasizes crop specialization. Farmers, especially in industrialized regions, often grow a single crop on most of their land, perhaps rotating it with a second crop in successive years: corn one year, for example, then soybeans, then back to corn. Such a strategy allows the farmer to reduce costs, but it also makes the crop, and, thus, the farmer and community, susceptible to widespread crop failure. When the crop is infested by any of an ever-changing number and variety of pests—worms, molds, bacteria, fungi, insects, or other diseases—the whole crop is likely to die quickly, unless an appropriate antidote is immediately applied. Chemical antidotes can do the job but increase pollution. Maintaining species diversity—growing several different crops instead of one or two—allows for crop failures without jeopardizing the entire income for a farm or region that specializes in a particular monoculture, such as tobacco, coffee, or bananas.

Chemicals are not the only methods of preventing crop loss. Genetically engineered seeds are one attempt at replacing post-infestation chemical treatments. For example, splicing genes into varieties of rice or potatoes from wholly unrelated species—say, hypothetically, grasshoppers—to prevent common forms of blight is occurring more often. Even if the new genes make the crop more resistant, however, they could trigger unknown side effects that have more serious long-term environmental and economic consequences than the problem they were used to solve. Genetically altered crops are essentially new life-forms being introduced into nature with no observable precedents to watch beforehand for clues as to what might happen.

Urban Sprawl. As more farms become mechanized, the need for farmers is being drastically reduced. There were more farmers in the United States in 1860 than there were in the year 2000. From a peak in 1935 of about 6.8 million farmers farming 1.1 billion acres, the United States at the end of the twentieth century counted fewer than 2 million farmers farming 950 million acres. As fewer people care for land, the potential for erosion and pollution to accelerate is likely to increase, causing land quality to decline.

As farmers are displaced and move into towns, the cities take up more space. The resulting urban sprawl converts a tremendous amount of cropland into parking lots, malls, industrial parks, or suburban neighborhoods. If cities were located in marginal areas, then the concern over the loss of farmland to commercial development would be nominal. However, the cities attracting the greatest numbers of people have too often replaced the best cropland. Taking the best cropland out of primary production imposes a severe economic penalty.

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World Food Supplies

All living things need food to begin the life process and to live, grow, work, and survive. Almost all foods that humans consume come from plants and animals. Not all of Earth's people eat the same foods, however, nor do they require the same caloric intakes. The types, combinations, and amounts of food consumed by different peoples depend upon historic, socioeconomic, and environmental factors.

The History of Food Consumption. Early in human history, people ate what they could gather or scavenge. Later, people ate what they could plant and harvest and what animals they could domesticate and raise. Modern people eat what they can grow, raise, or purchase. Their diets or food composition are determined by income, local customs, religion or food biases, and advertising. There is a global food market, and many people can select what they want to eat and when they eat it according to the prices they can pay and what is available.

Historically, in places where food was plentiful, accessible, and inexpensive, humans devoted less time to basic survival needs and more time to activities that led to human progress and enjoyment of leisure. Despite a modern global food system, instant telecommunications, the United Nations, and food surpluses at places, however, the problem of providing food for everyone on Earth has not been solved.

In 1996 leaders from 186 countries gathered in Rome, Italy, and agreed to reduce by half the number of hungry people in the world by the year 2015. United Nations data for 1998 revealed that more than 790 million people in the developing parts of the world did not have enough food to eat. This is more people than the total population of North America and Europe at that time. The number of undernourished people has been decreasing since 1990. At the current pace of hunger reduction in the world, 600 million will suffer from "acute food insecurity" and go to sleep hungry in 2015. Despite efforts being made to feed the world, outbreaks of food deficiencies, mass starvation, and famine are a certainty in the twenty-first century.

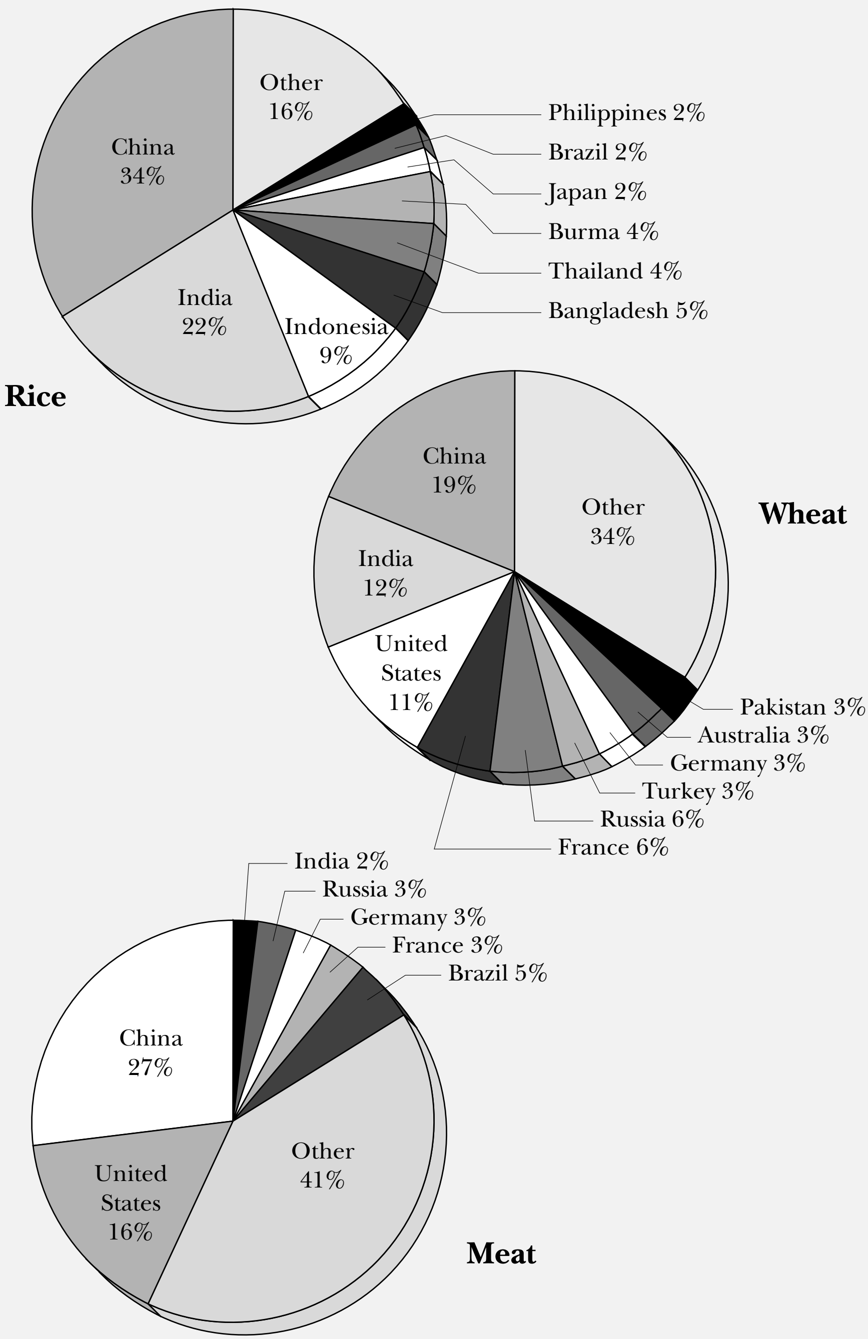
World Food Source Regions. Agriculture and related primary food production activities, such as fishing, hunting, and gathering, continue to employ more than one-third of the world's labor force. Agriculture's relative importance in the world economic system has declined with urbanization and industrialization, but it still plays a vital role in human survival and general economic growth. Agriculture in the third millennium must supply food to an increasing world population of nonfood producers. It must also produce food and nonfood crude materials for industry, accumulate capital needed for further economic growth, and allow workers from rural areas to enter industrial, construction, and expanding intraurban service functions.

Soil types, topography, weather, climate, socioeconomic history, location, population pressures, dietary preferences, stages in modern agricultural development, and governmental policies combine to give a distinctive personality to regional agricultural characteristics. Two of the most productive food-producing regions of the world are North America and Europe. Countries in these regions export large amounts of food to other parts of the world.

North America is one of the primary food-producing and food-exporting continents. After 1940 food output generally increased as cultivated acreage declined. Progress in improving the quantity and quality of food production is related to mechanization, chemicalization, improved breeding, and hybridization. Food output is limited more by market demands than by production obstacles.

Western Europe, although a basic food-deficit area, is a major producer

Percentages of World Production of Rice, Wheat, and Meat, by Country



Source: United Nations Food and Agriculture Organization (FAOSTAT Database, 2000).

and exporter of high-quality foodstuffs. After 1946 its agriculture became more profit-driven. Europe's agricultural labor force grew smaller, its agriculture became more mechanized, its farm sizes increased, and capital investment per acre increased.

Foods from Plants. Most basic staple foods come from a small number of plants and animals. Ranked by tonnage produced, the most important food plants throughout the world are wheats, corn (maize), rice, potatoes, cassava (manioc), barley, soybeans, sorghums and millets, beans, peas and chickpeas, and peanuts (groundnuts).

Wheat and rice are the most important plant foods. More than one-third of the world's cultivated land is planted with these two crops. Wheat is the dominant food staple in North America, Western and Eastern Europe, northern China, and the Middle East and North Africa. Rice is the dominant food staple in southern and eastern Asia. Corn, used primarily as animal food in developed nations, is a staple food in Latin America and Southeast Africa. Potatoes are a basic food in the highlands of South America and in Central and Eastern Europe. Cassava (manioc) is a tropical starch-producing root crop of special dietary importance in portions of lowland South America, the west coast countries of Africa, and sections of South Asia. Barley is an important component of diets in North African, Middle Eastern, and Eastern European countries. Soybeans are an integral part of the diets of those who live in eastern, southeastern, and southern Asia. Sorghums and millets are staple subsistence foods in the savanna regions of Africa and south Asia, while peanuts are a facet of dietary mixes in tropical Africa, Southeast Asia, and South America.

Food from Animals. Animals have been used as food by humans from the time the earliest people learned to hunt, trap, and fish. However, humans have domesticated only a few varieties of animals. Ranked by tonnage of meat produced, the most commonly eaten animals are cattle, pigs, chickens and turkeys, sheep, goats, water buffalo, camels, rabbits and guinea pigs, yaks, and llamas and alpacas.

Cattle, which produce milk and meat, are important food sources in North America, Western Europe, Eastern Europe, Australia and New Zealand, Argentina, and Uruguay. Pigs are bred and reared for food on a massive scale in southern and eastern Asia, North America, Western Europe, and Eastern Europe. Chickens are the most important domesticated fowl used as a human food source and are a part of the diets of most of the world's people. Sheep and goats, as a source of meat and milk, are especially important to the diets of those who live in the Middle East and North Africa, Eastern Europe, Western Europe, and Australia and New Zealand.

Water buffalo, camels, rabbits, guinea pigs, yaks, llamas, and alpacas are food sources in regions of the world where there is low consumption of meat for religious, cultural, or socioeconomic reasons. Fish is an inexpensive and wholesome source of food. Seafood is an important compo-

A distant relative of the camel, the South American llama was one of the few draft animals used in the pre-Columbian Americas and was also an important source of protein before Europeans brought cattle, sheep, and other animals. (Clyde L. Rasmussen)

nent to the diets of those who live in southern and eastern Asia, Western Europe, and North America.

The World's Growing Population. The problem of feeding the world is compounded by the fact that population was increasing at a rate of nearly 80 million persons per year at the end of the twentieth century. That rate of increase is roughly equivalent to adding a country the size of Germany to the world every single year.

Also compounding the problem of feeding the world are population redistribution patterns and changing food consumption standards. In the year 2000 the world population was projected to reach approximately ten billion people in 2050—four billion people more than were on the earth in 2000. Most of the increase in world population was expected to occur within the developing nations.

Urbanization. Along with an increase in population in developing nations is massive urbanization. City dwellers are food consumers, not food producers. The exodus of young men and women from rural areas has given rise to a new series of megacities, most of which are in developing countries. By the year 2015, twenty-six cities in the world are expected to have populations of ten million people or more.

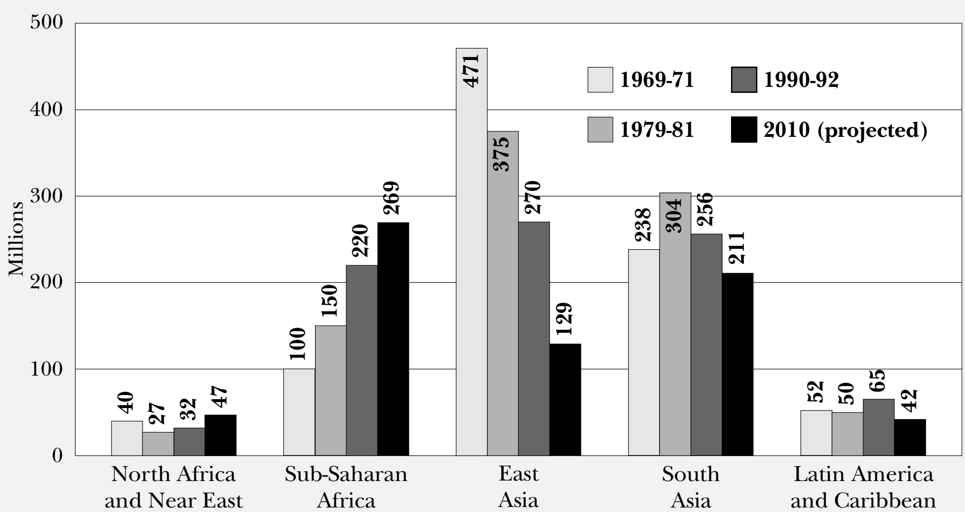
When rural dwellers move to cities, they tend to change their dietary composition and food-consumption patterns. Qualitative changes in dietary consumption standards are positive, for the most part, and are a result of copying the diets of what is considered a more prestigious group or positive educational activities of modern nutritional scientists working in developing countries. During the last four decades of the twentieth century, a tremendous shift took place in overall dietary habits. Dietary changes and consumption trends have contributed to a decrease in child mortality, an increase in longevity, and a greater resistance to disease. This globalization of people's diets has resulted in increased demands for higher quality, greater quantity, and more nutritious basic foods.

Strategies for Increasing Food Production. To meet the food demands and the food distribution needs of the world's people in the future, a grand strategy has been proposed. Its first step calls for the intensification of agriculture—improving biological, mechanical, and chemical technology and applying proven agricultural innovations to regions of the world where the physical and cultural environments are most suitable for rapid food production increases.

The second step in the strategy is to expand the areas where food is produced so that areas that are empty or underused will be made productive. Reclaiming areas damaged by human mismanagement, expanding irrigation in carefully selected areas, and introducing extensive agrotechniques to areas not under cultivation could increase the production of inexpensive grains and meats.

Finally, interregional, international, and global commerce should be expanded, in most instances, increasing regional specializations and production of high-quality, high-demand agricultural products for export

Number of Persons Chronically Undernourished in Developing Countries, by Region



Source: United Nations Food and Agriculture Organization (FAOSTAT Database, 2000).

and importing low-cost basic foods. A disequilibrium of supply and demand for certain commodities will persist, but food producers, regional and national agricultural planners, and those who strive for regional economic integration must take advantage of local conditions and location or create the new products needed by the food-consuming public in a one-world economy.

Perspectives. Humanity is entering a time of volatility in food production and distribution. The world will produce enough food to meet the demands of those who can afford to buy food. In many developing countries, however, food production is unlikely to keep pace with increases in the demand for food by growing populations. The food gap—the difference between production and demand—could more than double in the first three decades of the twenty-first century. Such a development would increase the dependence of developing countries on food imports. About 90 percent of the rate of increase in aggregate food demand in the early twenty-first century is expected to be the result of population increases.

Factors that could lead to larger fluctuations in food availability include weather variations such as those induced by El Niño and climatic change, the growing scarcity of water, civil strife and political instability, and declining food aid. In developing countries, decision makers need to ensure that policies promote broad-based economic growth—and in particular agricultural growth—so that their countries can produce enough food to feed themselves or enough income to buy the necessary food on the world market.

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Energy and Engineering

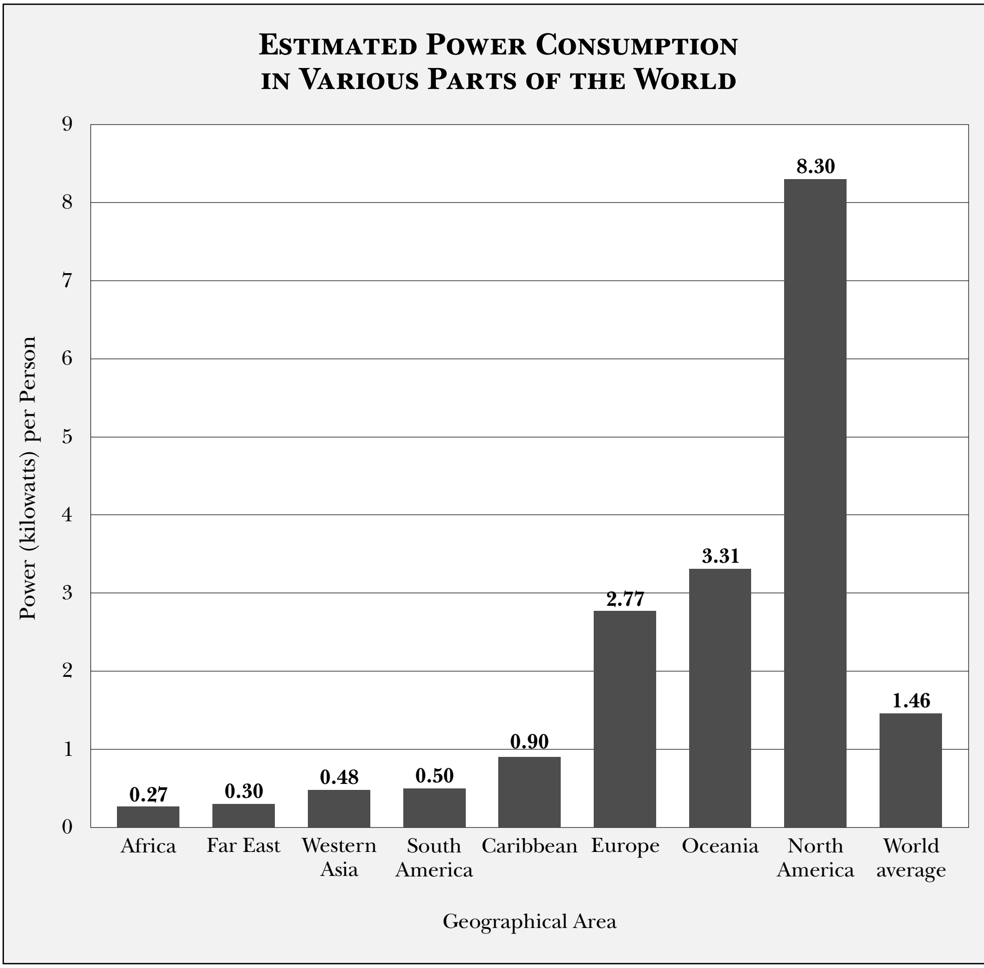
Energy Sources

Energy is essential for powering the processes of modern industrial society: refining ores, manufacturing products, moving vehicles, heating buildings, and powering appliances. In 1999 energy costs were half a trillion dollars in the United States alone. All technological progress has been based on harnessing more energy and using it more effectively. Energy use has been shaped by geography and also has shaped economic and political geography.

Ancient to Modern Energy. Energy use in traditional tribal societies illustrates all aspects of energy use that apply in modern human societies. Early Stone Age peoples had only their own muscle power, fueled by meat and raw vegetable matter. Warmth for living came from tropical or subtropical climates. Then a new energy source, fire, came into use. It made cold climates livable. It enabled the cooking of roots, grains, and heavy animal bones, vastly increasing the edible food supply. Its heat also hardened wood tools, cured pottery, and eventually allowed metalworking.

Nearly as important as fire was the domestication of animals, which multiplied available muscle energy. Domestic animals carried and pulled heavy loads. Domesticated horses could move as fast as the game to be hunted or large animals to be herded.

Increased energy efficiency was as important as new energy sources in making tribal societies more successful. Cured animal hides and woven cloth were additional factors enabling people to move to cooler climates. Cooking fires also allowed drying meat into jerky to preserve it against times of limited supply. Fire-cured pottery helped protect food against pests and kept water close by. However, energy benefits had costs. Fire drives for hunting may have caused major animal extinctions. Periodic burning of areas for primitive agriculture caused erosion. Trees became scarce near the best campsites because they had been used for camp fires—the first fuel shortage.



Energy Fundamentals. Human use of energy revolves about four interrelated factors: energy sources, methods of harnessing the sources, means of transporting or storing energy, and methods of using energy. The potential energies and energy flows that might be harnessed are many times greater than present use.

The Sun is the primary source of most energy on Earth. Sunlight warms the planet. Plants use photosynthesis to transform water and carbon dioxide into the sugars that power their growth and indirectly power plant-eating and meat-eating animals. Many other energies come indirectly from the Sun. Remains of plants and animals become fossil fuels. Solar heat evaporates water, which then falls as rain, causing water flow in rivers. Regional differences in the amount of sunlight received and reflected cause temperature differences that generate winds, ocean currents, and temperature differences between different ocean layers. Food for muscle power of humans and animals is the most basic energy system.

Energy Sources. Biomass—wood or other vegetable matter that can be burned—is still the most important energy source in much of the world. Its basic use is to provide heat for cooking and warmth. Biomass fuels are often agricultural or forestry wastes. The advantage of biomass is that it is grown, so it can be replaced. However, it has several limitations. Its low energy content per unit volume and unit mass makes it unprofitable to ship, so its use is limited to the amount nearby. Collecting and processing biomass fuels costs energy, so the net energy is less. Biomass energy production may compete with food production, since both come from the soil. Finally, other fuels can be cheaper.

Greater concentration of biomass energy or more efficient use would enable it to better compete against other energy sources. For example, fermenting sugars into fuel alcohol is one means of concentrating energy, but energy losses in processing make it expensive.

Fossil fuels have more concentrated chemical energy than biomass. Underground heat and pressure compacts trees and swampy brush into the progressively more energy-concentrated peat, lignite coal, bituminous coal, and anthracite or black coal, which is mostly carbon. Industrializing regions turned to coal when they had exhausted their firewood. Like wood, coal could be stored and shoveled into the fire box as needed. Large deposits of coal are still available, but growth in the use of coal slowed by the mid-twentieth century because of two competing fossil fuels, petroleum and natural gas.

Firewood is the oldest and most widespread fuel and remains an important source of heat in most parts of the world. (Digital Stock)

Petroleum includes gasoline, diesel fuel, and fuel oil. It forms from remains of one-celled plants and animals in the ocean that decompose from sugars into simpler hydrogen and carbon compounds (hydrocarbons). Petroleum yields more energy per unit than coal, and it is pumped rather than shoveled. These advantages mean that an oil-fired vehicle can be cheaper and have greater range than a coal-fired vehicle.

There are also hydrocarbon gases associated with petroleum and coal. The most common is the natural gas methane. Methane does not have the energy density of hydrocarbon liquids, but it burns cleanly and is a fuel of choice for end uses such as heating homes and businesses.

Petroleum and natural gas deposits are widely scattered throughout the world, but the greatest known deposits are in an area extending from Saudi Arabia north through the Caucasus Mountains. Deposits extend

Offshore oil rig. Continental margins are the principal areas in which offshore drilling is conducted; they constitute approximately 21 percent of the surface area of the oceans and may contain a majority of the world's future reserves of oil and gas. (PhotoDisc)

After underground oil resources are found by drilling, their contents are pumped to the surface. (PhotoDisc)

out to sea in areas such as the Persian Gulf, the North Sea, and the Gulf of Mexico. More exotic sources, such as oil tar sands and shale oil, could be tapped when conventional supplies run low.

Heat engines transform the potential of chemical energies. James Watt's steam engine (1782) takes heat from burning wood or coal (external combustion), boils water to steam, and expands it through pistons to make mechanical motion. In the twentieth century, propeller-like steam turbines were developed to increase efficiency and decrease complexity. Auto and diesel engines burn fuel inside the engine (internal combustion), and the hot gases expand through pistons to make mechanical motion. Expanding them through a gas turbine is a jet engine. Heat engines can create energy from other sources, such as concentrated sunlight, nuclear fission, or nuclear fusion. The electrical generator transforms mechanical motion into electricity that can move by wire to uses far away. Such transportation (or wheeling) of electricity means that one power plant can serve many customers in different locations.

Flowing water and wind are two of the oldest sources of industrial power. The Industrial Revolution began with water power and wind power, but they could only be used in certain locations, and they were not as dependable as steam engines. In the early twentieth century, electricity made river power practical again. Large dams along river valleys with adequate water and steep enough slopes enabled areas like the Tennessee Valley to be industrial centers. In the 1970's wind power began to be used again, this time for generating electricity.

The Soviet Union so revered nuclear fission that its government erected a monument to the splitting the atom. (PhotoDisc)

Solar energy can be tapped directly for heat or to make electricity. Although sunlight is free, it is not concentrated energy, so getting usable energy requires more equipment cost. Consequently, fossil-fueled heat is cheaper than solar heat, and power from the conventional utility grid has been much less expensive than solar-generated electricity. However, prices of solar equipment are dropping as technologies improve, and prices of other energy sources may rise.

Future Energy Sources. Possible future energy sources are nuclear fission, nuclear fusion, geothermal heat, and tides. Fission reactors contain a critical mass of radioactive heavy elements that sustains a chain reaction of atoms splitting (fissioning) into lighter elements—releasing heat to run a steam turbine. Tremendous amounts of fission energy are available, but reactor costs and safety issues have kept nuclear prices higher than that of coal.

Nuclear fusion involves the same reaction that powers the Sun: four hydrogen atoms fusing into one helium atom. However, duplicating the Sun's heat in a small area without damaging the surrounding reactor may be too expensive to allow profitable fusion reactors.

Geothermal power plants, tapping heat energy from within the earth, have operated since 1904, but widespread use depends on cheaper drilling to make them practical in more than highly volcanic areas. Tidal power is limited to the few bays that concentrate tidal energy.

Energy and Warfare. Much of ancient energy use revolved about herding animals and conducting warfare. Horse riders moved faster and hit harder than warriors on foot. The bow and arrow did not change appreciably for thousands of years. Herders on the plains rode horses and used the bow and arrow as part of tending their flocks, and the small amounts of metal needed for weapons was easily acquired. Consequently, the herders could invade and plunder much more advanced peoples. From Scythians to Parthians to Mongols, these people consistently destroyed the more advanced civilizations.

The geographical effect was that ancient civilizations generally developed only if they had physical barriers separating them from the flat plains of herding peoples. Egypt had deserts and seas. The Greeks and Romans lived on mountainous peninsulas, safe from easy attack. The Chinese built the Great Wall along their northern frontier to block invasions.

Barbarian riders dominated until the advent of an energy system of gunpowder and steel barrels began delivering lead bullets. With them, the Russians broke the power of the Tartars in Eurasia in the late fifteenth century, and various peoples from Europe conquered most of the world. Energy and industrial might became progressively more important in war with automatic weapons, high explosives, aircraft, rockets, and nuclear weapons.

By World War II, oil had become a reason for war and a crucial input for war. The Germans attempted to seize petroleum fields around Baku on the Caspian. Later in the war, major Allied attacks targeted oil fields in Romania and plants in Germany synthesizing liquid fuels. During the Arab-Israeli War of 1973, Arabs countered Western support of Israel with an oil boycott that rocked Western economies. In 1990 Iraq attempted to solve a border dispute with its oil-rich neighbor, Kuwait, by seizing all of Kuwait. An alliance, led by the United States, ejected the Iraqis.

Other wars occur over petroleum deposits that extend out to sea. European nations bordering on the North Sea negotiated a complete demarcation of economic rights throughout that body. There has been no similar negotiation regarding the South China Sea, which may have deposits comparable to those in the Saudi Peninsula. The area is claimed by China, Vietnam, Malaysia, and the Philippines. Turkey and Greece have not resolved ownership division of Aegean waters that might have oil deposits.

Energy, Development, and Energy Efficiency. Ancient civilizations tended to grow and use locally available food and firewood. Soils and wood supplies often were depleted at the same time, which often coincided with declines in those civilizations. The Industrial Revolution caused development to concentrate in new wooded areas where rivers suitable for power, iron ore, and coal were close together, for example, England, Silesia, and the Pittsburgh area. The iron ore of Alsace in France combined with nearby coal from the Ruhr in Germany fueled tremendous growth, not always peacefully.

By the late nineteenth century, the development of Birmingham, Alabama, demonstrated that railroads enabled a wider spread between coal deposits, iron ore deposits, and existing population centers. By the 1920's, the Soviet Union developed entirely new cities to connect with resources. By the 1970's, unit trains and ore-carrying ships transported coal from the thick coal beds in Montana and Wyoming to the United States' East Coast and to countries in Asia.

The mechanized transport of electrical distribution and distribution of natural gas in pipelines also changed settlement patterns. Trains and subway trains allowed cities to spread along rail corridors in the late nineteenth century and early twentieth century. By the 1940's, cars and trucks enabled cities such as Los Angeles and Phoenix to spread into suburbs. The trend continues with independent solar power that allows houses to be sited anywhere.

Advances in technology have allowed people to get more while using less energy. For example, early peoples stampeded herds of animals over cliffs for food, which was mostly wasted. Horseback hunting was vastly more efficient. Likewise, fireplaces in colonial North America were inefficient, sending most of their heat up the chimney. In the late eighteenth century, inventor and statesman Benjamin Franklin developed a metallic cylinder radiating heat in all directions, which saved firewood.

The ancient Greeks and others pioneered the use of passive solar energy and efficiency after they exhausted available firewood. They sited buildings to absorb as much low winter sun as possible and constructed overhanging roofs to shade buildings from the high summer sun. That siting was augmented by heavy masonry building materials that buffered the buildings from extremes of heat and cold. Later, metal pipes and glass meant that solar energy could be used for water and space heating.

The first seven decades of the twentieth century saw major declines in energy prices, and cars and appliances became less efficient. That changed abruptly with the energy crises and high prices of the 1970's. Since then, countries such as Japan, with few local energy resources, have worked to increase efficiency so they will be less sensitive to energy shocks and be able to thrive with minimal energy inputs. This trend could lead eventually to economies functioning on only solar and biomass inputs.

Solid-state electronics, use of fluorescent lights rather than incandescent, and fuel cells, which convert fuel directly into electricity more efficiently than combustion engines, all could lead to less energy use. The speed of their adoption depends on the price of competing energies. Predictions that petroleum resources will be exhausted started in 1866; however, this is unlikely to happen before the middle of the twenty-first century. First, drilling will likely go to more exotic locations, and eventually to oil tars, such as those of Venezuela, oil shales in western Canada, and methane hydrates, which are deposits of methane frozen together with water ice on the ocean floors.

Energy and Environment. Energy affects the environment in three major ways. First, firewood gathering in underdeveloped countries contributes to deforestation and resulting erosion. Although more efficient stoves and small solar cookers have been designed, efficiency increases are competing against population increases.

Energy production also frequently causes toxic pollutant by-products. Sulfur dioxide (from sulfur impurities in coal and oil) and nitrogen oxides (from nitrogen being formed during combustion) damage lungs and corrode the surfaces of buildings. Lead additives in gasoline make internal combustion engines run more efficiently, but they cause low-grade lead poisoning. Spent radioactive fuel from nuclear fission reactors is so poisonous that it must be guarded for centuries.

Finally, carbon dioxide from the burning of fossil fuels may be accelerating the greenhouse effect, whereby atmospheric carbon dioxide slows the planetary loss of heat. If the effect is as strong as some research suggests, global temperatures may increase several degrees on average in the twenty-first century, with unknown effects on climate and sea level.

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Information on the World Wide Web

The International Energy Agency (IEA) is an energy forum of twenty-three industrialized countries committed to sharing information and taking joint measures to meet oil supply emergencies. The IEA's Web site provides information about the agency's activities and research. (www.iea.org)

Alternative Energies

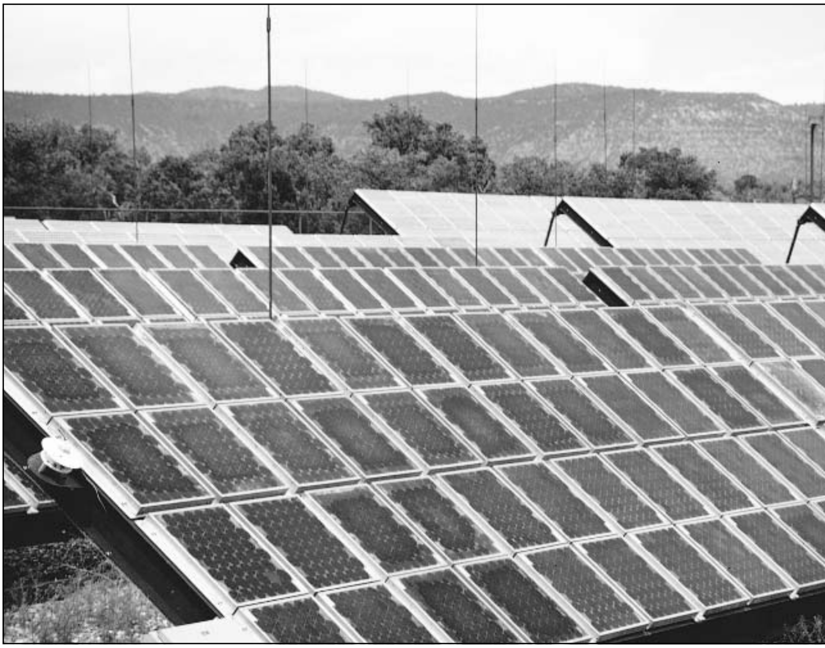
The energy that lights homes and powers industry is indispensable in modern societies. This energy usually comes from mechanical energy that is converted into electrical energy by means of generators—complex machines that harness basic energy captured when such sources as coal, oil, or wood are burned under controlled conditions. This energy, in turn, provides the thermal energy used for heating, cooling, and lighting and for powering automobiles, locomotives, steamships, and airplanes. Because such natural resources as coal, oil, and wood are being used up, it is vital that these nonrenewable sources of energy be replaced by sources that are renewable and abundant. It is also desirable that alternative sources of energy be developed in order to cut down on the pollution that results from the combustion of the hydrocarbons that make the nonrenewable fuels burn.

The Sun as an Energy Source. Energy is heat. The Sun provides the heat that makes Earth habitable. As today's commonly used fuel resources are used less, solar energy will be used increasingly to provide the power that societies need in order to function and flourish.

There are two forms of solar energy: passive and active. Humankind has long employed passive solar energy, which requires no special equipment. Ancient cave dwellers soon realized that if they inhabited caves that faced the Sun, those caves would be warmer than those that faced away from the Sun. They also observed that dark surfaces retained heat and that dark rocks heated by the Sun would radiate the heat they contained after the Sun had set. Modern builders often capitalize on this same knowledge by constructing structures that face south in the Northern Hemisphere and north in the Southern Hemisphere. The windows that face the Sun are often large and unobstructed by draperies and curtains. Sunlight beats through the glass and, in passive solar houses, usually heats a dark stone or brick floor that will emit heat during the hours when there is no sunlight. Just as an automobile parked in the sunlight will become hot and retain its heat, so do passive solar buildings become hot and retain their heat.

Active solar energy is derived by placing specially designed panels so that they face the Sun. These panels, called flat plate collectors, have a flat glass top beneath which is a panel, often made of copper with a black overlay of paint, that retains heat. These panels are constructed so that heat cannot escape from them easily. When water circulated through pipes in the panels becomes hot, it is either pumped into tanks where it can be stored or circulated through a central heating system.

Some active solar devices are quite complex and best suited to industrial use. Among these is the focusing collector, a saucer-shaped mirror that centers the Sun's rays on a small area that becomes extremely hot. A power plant at Odeillo in the French Pyrenees Mountains uses such a sys-



Solar panels used to collect sunlight for solar energy. (PhotoDisc)

tem to concentrate the Sun's rays on a concave mirror. The mirror directs its incredible heat to an enormous, confined body of water that the heat turns to steam, which is then used to generate electricity.

Another active solar device is the solar or photovoltaic cell, which gathers heat from the Sun and turns it into energy directly. Such cells help to power spacecraft that cannot carry enough conventional fuel to sustain them through long missions in outer space.

Geothermal Heating. The earth's core is incredibly hot. Its heat extends far into the lower surfaces of the planet, at times causing eruptions in the form of geysers or volcanoes. Many places on Earth have springs that are warmed by heat from the earth's core.

In some countries, such as Iceland, warm springs are so abundant that people throughout the country bathe in them through the coldest of winters. In Iceland, geothermal energy is used to heat and light homes, making the use of fossil fuels unnecessary.

Hot areas exist beneath every acre of land on Earth. When such areas are near the surface, it is easy to use them to produce the energy that humans require. As dependence on fossil fuels decreases, means will increasingly be found of drawing on Earth's subterranean heat as a major source of energy.

Wind Power. Anyone who has watched a sailboat move effortlessly through the water has observed how the wind can be used as a source of

Spanish windmills. The simple windmill is one of the oldest and most efficient machines for harnessing alternative energy. (PhotoDisc)

kinetic energy—the kind of energy that involves motion—whose movement is transferred to objects that it touches. Wind power has been used throughout human history. In its more refined aspects, it has been employed to power windmills that cause turbines to rotate, providing generators with the power they require to produce electricity.

Windmills typically have from two to twenty blades made of wood or of heavy cloth such as canvas. Windmills are most effective when they are located in places where the wind regularly blows with considerable velocity. As their blades turn, they cause the shafts of turbines to rotate, thus powering generators. The electricity created is usually transmitted over metal cables for immediate use or for storage.

Modern vertical-axis wind turbines have two or three strips of curved metal that are attached at both ends to a vertical pole. They can operate efficiently even if they are not turned toward the wind. These windmills are a great improvement over the old horizontal axis windmills that have been in use for many years. Although older wind machines did not produce sufficient power for whole communities, the Department of Energy is experimenting with vertical-axis machines that it estimates could some day meet 20 percent of the energy needs of the United States, cheaply and without pollution.

Ocean Energy

The oceans have tremendous untapped energy flows in currents and tremendous potential energy in the temperature differences between warmer tropical surface waters and colder deep waters, known as ocean thermal energy conversion. In both cases, the insurmountable cost has been in transporting energy to users on shore.

Oceans as Energy Sources. Seventy percent of the earth's surface is covered by oceans. Their tides, which rise and fall with predictable regularity twice a day, would offer a ready source of energy once it becomes economically feasible to harness them and store the electrical energy they can provide. The most promising spots to build facilities to create electrical energy from the tides are places where the tides are regularly quite dramatic, such as Nova Scotia's Bay of Fundy, where the difference between high and low tides averages about 55 feet (17 meters).

Some tidal power stations that currently exist were created by building dams across estuaries. The sluices of these dams are opened when the tide comes in and closed after the resulting reservoir fills. The water captured in the reservoir is held for several hours until the tide is low enough to create a considerable difference between the level of the water in the reservoir and that outside it. Then the sluice gates are opened and, as the water rushes out at a high rate of speed, it turns turbines that generate electricity.

Future of Renewable Energy. As pollution becomes a huge problem throughout the world, the race to find nonpolluting sources of energy is accelerating rapidly. New technologies are making renewable energy sources economically practical. As supplies of fossil fuels have diminished, pressure to become less dependent on them has grown worldwide. Alternative energy sources are the wave of the future.

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Engineering Projects

Human beings attempt to overcome the physical landscape by building forms and structures on the earth. Most structures are small-scale, like houses, telephone poles, and schools. Other structures are great engineering works, such as hydroelectric projects, dams, canals, tunnels, bridges, and buildings.

Hydroelectric Projects. The potential for hydroelectricity generation is greatest in rapidly flowing rivers in mountainous or hilly terrain. The moving water turns turbines that, in turn, generate electricity. Hydroelectric power projects also can be built on escarpments and fall lines, where there is tremendous untapped energy in the falling water.

Most of the potential for hydroelectricity remains untapped. Only about one-sixth of the suitable rivers and falls are used for hydroelectric power. Certain areas of the world have used more of their potential than others. The United States, most of Western Europe, Japan, South Korea, and Australia have all tapped about three-fourths of their potential for water power. Brazil, Paraguay, Mexico, and Canada also use significant portions of their hydroelectric potential. Russia, the former Soviet Republics, China, Pakistan, and India have tremendous potential that is not yet fully tapped, but they still produce a significant proportion of the world's hydroelectric power.

Most of the remaining areas of the world have not yet taken advantage of hydroelectric power. In South America, there is great potential for exploiting water power in most areas, especially Colombia, Ecuador, Peru, and Argentina. In Africa, only Zambia, Zimbabwe, and Ghana produce significant hydroelectricity. In the late 1990's, the Democratic Republic of the Congo (formerly Zaire) showed the greatest promise for the future, but it had not yet tapped this resource.

In Southeast Asia, only Thailand and Vietnam have used much of their potential, and even that is not a great amount. The greatest potential in that region lies in Indonesia, New Guinea, and Myanmar (Burma).

Dams. Dams serve several purposes. One purpose is the generation of hydroelectric power, as discussed above. Dams also provide flood control and irrigation. Rivers in their natural state tend to rise and fall with the seasons. This can cause serious problems for people living in downstream valleys. Flood-control dams also can be used to regulate the flow of water used for irrigation and other projects. A final reason to build dams is to reduce swampland, in order to control insects and the diseases they carry.

Famous dams are found in all regions of the world. In North America, two of the most notable dams are Hoover Dam, completed in 1936, on the Colorado River between Arizona and Nevada; and the Grand Coulee Dam, completed in 1942, on the Columbia River in Washington State.

In South America, the most famous dam is the Itaipu Dam, completed in 1983, on the Paraná River between Brazil and Paraguay. In Africa, the Aswan High Dam was completed in 1970, on the Nile River in Egypt, and the Kariba Dam was completed in 1958, on the Zambezi River between Zambia and Zimbabwe. In Asia, the Three Gorges Dam was under construction on the Chiang Jiang (Yangtze River) in China during the late 1990's, with completion scheduled for 2009.

Bridges. Bridges are built to span low-lying land between two high places. Most commonly, there is a river or other body of water in the way, but other features that might be spanned include ravines, deep valleys and trenches, and swamps. A related engineering project is the causeway, in which land in a low-lying area is built up and a road is then constructed on it.

The longest bridge in the world is the Akashi Kaikyo in Japan near Osaka. It was built in 1998 and spans 6,529 feet (1,990 meters), connecting the island of Hōnshū to the small island of Awaji. The Storebælt Bridge in Denmark, also completed in 1998, spans 5,328 feet (1,624 meters), connecting the island of Sjaelland, on which Copenhagen is situated, with the rest of Denmark. Another bridge spanning more than 5,300 feet is the Izmit Bay Bridge in Turkey, which was being built near Istanbul in the late 1990's.

Tenpozan Watasi bridge in Osaka, Japan. (PhotoDisc)

Other long bridges can be found across the Humber River in Hull, England; across the Chiang Jiang (Yangtze River) in China; in Hong Kong, Norway, Sweden, and Turkey and elsewhere in Japan.

The longest bridge in the United States, which was once the longest in the world, is the Verrazano-Narrows Bridge in New York City between Staten Island and Brooklyn. Completed in 1964, it spans 4,260 feet (1,298 meters). Only slightly shorter—at 4,200 feet—is the San Francisco Bay Bridge, which was completed in 1937.

Canals. Moving goods and people by water is generally cheaper and easier, if a bit slower, than moving them by land. Before the twentieth century, that cost savings overwhelmed the advantages of land travel—speed and versatility. Therefore, human beings have wanted to move things by water whenever possible. To do so, they had two choices: locate factories and people near water, such as rivers, lakes, and oceans, or bring water to where the factories and people are, by digging canals.

One of the most famous canals in the world is the Erie Canal, which runs from Albany to Buffalo in New York State. Built in 1825 and running a length of 363 miles (584 km.), the Erie Canal opened up the Great Lakes region of North America to development and led to the rise of New York City as one of the world's dominant cities.

Two other important canals in world history are the Panama Canal and the Suez Canal. The Panama Canal connects the Atlantic and Pacific Oceans over a length of 50.7 miles (81.6 km.) on the isthmus of Panama in Central America. Completed in 1914, the Panama Canal eliminated the long and dangerous sea journey around the tip of South America. The Suez Canal in Egypt, which runs for 100 miles (162 km.) and was

Canal in the Netherlands. Canal construction is an ancient engineering technology that was perfected in the mid-eighteenth century. Before modern engines, canals were simple water-beds of uniform width and depth bordered by towpaths on which animals or men towed barges on the water. (PhotoDisc)

Engineering Works and Environmental Problems

Although engineering allows humans to overcome natural obstacles, works of engineering often have unintended consequences. Many engineering projects have caused unanticipated environmental problems.

Dams, for instance, create large lakes behind them by trapping water that is released slowly. This water typically contains silt and other material that eventually would have formed soil downstream had the water been allowed to flow naturally. Instead, the silt builds up behind the dam, eventually diminishing the lake's usefulness. As an additional consequence, there is less silt available for soil-building downstream.

Canals also can cause environmental harm by diverting water from its natural course. The river from which water is diverted may dry up, negatively affecting fish, animals, and the people who live downstream.

The benefits of engineering works must be weighed against the damage they do to the environment. They may be worthwhile, but they are neither all good nor all bad: There are benefits and drawbacks in building any engineering project.

completed in 1856, eliminates a similar journey around the Cape of Good Hope in South Africa.

The longest canal in the world is the Grand Canal in China, which was built in the seventh century and stretches a length of 1,085 miles (2,904 km.). It connects Tianjin, near Beijing in the north of China, with Nanjing on the Chang Jiang (Yangtze River) in Central China. This canal may eventually be surpassed in length by the Karakum Canal, which runs across the Central Asian desert in Turkmenistan from the Amu Darya River westward to Ashkhabad. That canal was begun in the 1950's and was intended to irrigate the dry lands of Turkmenistan and eventually to reach the Caspian Sea. The project has stalled at a length of 700 miles (1,100 km.) and it is not known if it will ever be completed.

Many canals are found in Europe, particularly in England, France, Belgium, the Netherlands, and Germany, and in the United States and Canada, especially connecting the Great Lakes to each other and to the Ohio and Mississippi Rivers.

Tunnels. Tunnels connect two places separated by physical features that would make it extremely difficult, if not impossible, for them to be connected without cutting directly through them. Tunnels can be used in place of bridges over water bodies so that water traffic is not impeded by a bridge span. Tunnels of this type are often found in port cities, and cities with them include Montreal, Quebec; New York City; Hampton Roads, Virginia; Liverpool, England; or Rio de Janeiro, Brazil.

Tunnels are often used to go through mountains that might be too tall to climb over. Trains especially are sensitive to changes in slope, and train tunnels are found all over the world. Less common are automobile and truck tunnels, although these are also found in many places. Train and automotive tunnels through mountains are common in the Appalachian Mountains in Pennsylvania, the Rockies in the United States and Canada, Japan, and the Alps in Italy, France, Switzerland, and Austria.

The Chunnel. Arguably the most famous—and one of the most ambitious—tunnels in the world goes by the name Chunnel. Completed in 1994, it connects Dover, England, to Calais, France, and runs 31 miles (50 km.). "Chunnel" is short for the Channel Tunnel, named for the English Channel, the body of water that it goes under. It was built as a train tunnel, but cars and trucks can be carried through it on trains. In the year 2000 plans were underway to cut a second tunnel, to carry automobiles and trucks, that would run parallel to the first Chunnel.

Among undersea tunnels, the Chunnel is exceeded in length only by the Seikan Tunnel in Japan, which connects the large island of Hōnshū with the northern island of Hokkaidō. The Seikan Tunnel is nearly 2.4 miles (4 km.) longer than Europe's Chunnel.

Buildings. Historically, North America has been home to the tallest buildings in the world. Chicago has been called the birthplace of the sky-

New York City's World Trade Center towers. (PhotoDisc) scraper and was at one time home to the world's tallest building. In 1998, however, the two Petronas Towers (each 1,483 feet/452 meters tall) were completed in Kuala Lumpur, Malaysia, surpassing the height of the world's tallest building, Chicago's Sears Tower (1,450 feet/442 meters), which had been completed in 1974. Not to be outdone, plans were made in Chicago in the late 1990's to build a new skyscraper, called the 7 South Dearborn Building, which would be 1,550 feet (472 meters) in height when it was completed in 2003.

Other famous tall buildings are found primarily in cities of North America and East and Southeast Asia. The Jin Mao Building in Shanghai, China, was completed in 1999, at a height of 1,380 feet (421 meters). New York City has long been home to some of the world's tallest buildings. Until they collapsed when hijacked airliners struck them in September, 2001, the tallest of the city's buildings were the twin towers of the World Trade Center in Lower Manhattan. The towers were completed in 1972 and 1973 and reached heights of 1,368 feet (417 meters) and 1,362 feet (415 meters). Also in New York are the Empire State Building at a height of 1,250 feet (381 meters) and the Chrysler Building at 1,046 feet (319 meters). These both were finished in the 1930's and were the two tallest buildings in the world until the John Hancock Center was finished in Chicago in 1969, at 1,127 feet (344 meters).

Hong Kong and the Pearl River region of China boast several tall buildings. Citic Plaza in Guangzhou, China, was completed in 1997 at a height of 1,283 feet (391 meters). Shun Hing Square in Shenzhen, China, was completed a year earlier and stands 1,260 feet (384 meters).

The tallest building in Europe is Commerzbank Tower in Frankfurt, Germany, completed in 1997 at 981 feet (299 meters). In Australia, Rialto Tower in Melbourne was built in 1985 and stands 813 feet (248 meters). There are no buildings over 750 feet (228 meters) in South America or Africa.

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Industry and Trade

Minerals

Mineral resources make up all the nonliving matter found in the earth, its atmosphere, and its waters that are useful to humankind. The great ages of history are classified by the resources that were exploited. First came the Stone Age, when flint was used to make tools and weapons. The Bronze Age followed; it was a time when metals such as copper and tin began to be extracted and used. Finally came the Iron Age, the time of steel and other ferrous alloys that required higher temperatures and more sophisticated metallurgy.

Metals, however, are not the whole story—economic progress also requires fossil fuels such as coal, oil, natural gas, tar sands, or oil shale as energy sources. Beyond metals and fuels, there are a host of mineral resources that make modern life possible: building stone, salt, atmospheric gases (oxygen, nitrogen), fertilizer minerals (phosphates, nitrates, and potash), sulfur, quartz, clay, asbestos, and diamonds are some examples.

Mining and Prospecting. Exploitation of mineral resources begins with the discovery and recognition of the value of the deposits. To be economically viable, the mineral must be salable at a price greater than the

A worker in Thailand prepares piles of salt for marketing. Sodium chloride—which we know as ordinary table salt—is an important mineral resource throughout the world. (Clyde L. Rasmussen)

Large-scale strip mine. Strip mining is simpler and cheaper to undertake than underground mining, but it does heavy—and often irreparable—damage to the environment. (PhotoDisc)

cost of its extraction, and great care is taken to determine the probable size of a deposit and the labor involved in isolating it before operations begin. Iron, aluminum, copper, lead, and zinc occur as mineral ores that are mined, then subjected to chemical processes to separate the metal from the other elements (usually oxygen or sulfur) that are bonded to the metal in the ore.

Some deposits of gold or platinum are found in elemental (native) form as nuggets or powder and may be isolated by alluvial mining—using running water to wash away low-density impurities, leaving the dense metal behind. Most metal ores, however, are obtained only after extensive digging and blasting and the use of large-scale earthmoving equipment. Surface mining or strip mining is far simpler and safer than underground mining.

Safety and Environmental Considerations. Underground mines can extend as far as a mile into the earth and are subject to cave-ins, water leakage, and dangerous gases that can explode or suffocate miners. Safety is an overriding issue in deep mines, and there is legislation in many countries designed to regulate mine safety and to enforce practices that reduce hazards to the miners from breathing dust or gases.

In the past, mining often was conducted without regard to the effects on the environment. In economically advanced countries such as the

Contaminated water caused by mining in Idaho Springs, Colorado, in the early 1980's. (U.S. Geological Survey)

United States, this is now seen as unacceptable. Mines are expected to be filled in, not just abandoned after they are worked out, and care must be taken that rivers and streams are not contaminated with mine wastes.

Iron, Steel, and Coal. Iron ore and coal are essential for the manufacture of steel, the most important structural metal. Both raw materials occur in many geographic regions. Before the mid-nineteenth century, iron was smelted in the eastern United States—New Jersey, New York, and Massachusetts—but then huge hematite deposits were discovered near Duluth, Minnesota, on Lake Superior. The ore traveled by ship to steel mills in northwest Indiana and northeast Illinois, and coal came from Illinois or Ohio. Steel also was made in Pittsburgh and Bethlehem in Pennsylvania, and in Birmingham, Alabama.

After World War II, the U.S. steel industry was slow to modernize its facilities, and after 1970 it had great difficulty producing steel at a price that could compete with imports from countries such as Japan, Korea, and Brazil. In Europe, the German steel industry centered in the Ruhr River valley in cities such as Essen and Düsseldorf. In Russia, iron ore is mined in the Urals, in the Crimea, and at Krivoi Rog in Ukraine. Elsewhere in Europe, the French "minette" ores of Alsace-Lorraine, the Swedish magnetite deposits near Kiruna, and the British hematite deposits in Lancashire are all significant. Hematite is also found in Labrador, Canada, near the Quebec border.

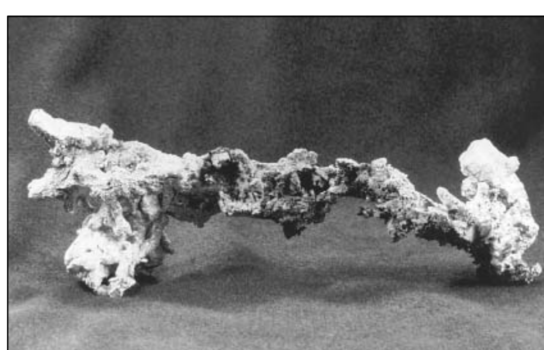
Coal is widely distributed on earth. In the United States, Kentucky, West Virginia, and Pennsylvania are known for their coal mines, but coal is also found in Illinois, Indiana, Ohio, Montana, and other states. Much of the anthracite (hard coal) is taken from underground mines, where networks of tunnels are dug through the coal seam, and the coal is loosened by blasting, use of digging machines, or human labor. A huge deposit of brown coal is mined at the Yallourn open pit mine west of Melbourne, Australia. In Germany, the mines are near Garsdorf in Nord-Rhein/Westfalen, and in the United Kingdom, coal is mined in Wales. South Africa has coal and is a leader in manufacture of liquid fuels from coal. There is coal in Antarctica, but it cannot yet be mined profitably. China and Japan both have coal mines, as does Russia.

Aluminum. Aluminum is the most important structural metal after iron. It is extremely abundant in the earth's crust, but the only readily extractable ore is bauxite, a hydrated oxide usually contaminated with iron and silica. Bauxite was originally found in France but also exists in many other places in Europe, as well as in Australia, India, China, the former Soviet Union, Indonesia, Malaysia, Suriname, and Jamaica.

Much of the bauxite in the United States comes from Arkansas. After purification, the bauxite is combined with the mineral cryolite at high temperature and subjected to electrolysis between carbon electrodes (the Hall-Héroult process), yielding pure aluminum. Because of the enormous electrical energy requirements of the Hall-Héroult method, aluminum can be made economically only where cheap power (preferably hydroelectric) is available. This means that the bauxite often must be shipped long distances—Jamaican bauxite comes to the United States for electrolysis, for example.

Copper, Silver, and Gold. These coinage metals have been known and used since antiquity. Copper came from Cyprus and takes its name from the name of the island. Copper ores include oxides or sulfides (cuprite, bornite, covellite, and others). Not enough native copper occurs to be commercially significant. Mines in Bingham, Utah, and Ely, Nevada, are major sources in the United States. The El Teniente mine in Chile is the world's largest copper mine, and major amounts of copper also come from Canada, the former Soviet Union, and the Katanga region mines in Congo-Kinshasa and Zambia.

Silver often occurs native, as well as in combination with other metals, including lead, copper, and gold. Famous silver mines in the United States include those near Virginia City (the Comstock lode) and Tonopah, Nevada, and Coeur d'Alene, Idaho.



Silver ore in its native state. (U.S. Geological Survey)

Silver has been mined in the past in Bolivia (Potosi mines), Peru (Cerro de Pasco mines), Mexico, and Ontario and British Columbia in Canada.

Gold occurs native as gold dust or nuggets, sometimes with silver as a natural alloy called electrum. Other gold minerals include selenides and tellurides. Small amounts of gold are present in sea water, but attempts to isolate gold economically from this source have so far failed. Famous gold rushes occurred in California and Colorado in the United States, Canada's Yukon, and Alaska's Klondike region. Major gold-producing countries include South Africa, Siberia, Ghana (once called the Gold Coast), the Philippines, Australia, and Canada.

Petroleum and Natural Gas. Petroleum has been found on every continent except Antarctica, with 600,000 producing wells in one hundred different countries. In the United States, petroleum was originally discovered in Pennsylvania, with more important discoveries being made later in west Texas, Oklahoma, California, and Alaska. New wells are often drilled offshore, for example in the Gulf of Mexico or the North Sea. The United States depends heavily on oil imported from Mexico, South America, Saudi Arabia and the Persian Gulf states, and Canada.

Over the years, the price of oil has varied dramatically, particularly due to the attempts of the Organization of Petroleum Exporting Countries (OPEC) to limit production and drive up prices. In Europe, oil is produced in Azerbaijan near the Caspian Sea, where a pipeline is planned to carry the crude to the Mediterranean port of Ceyhan, in Turkey. In Africa, there are oil wells in Gabon, Libya, and Nigeria; in the Persian Gulf region, oil is found in Kuwait, Qatar, Iran, and Iraq. Much crude oil travels in huge tankers to Europe, Japan, and the United States, but some supplies refineries in Saudi Arabia at Abadan. Tankers must exit the Persian Gulf through the narrow Gulf of Hormuz, which thus assumes great strategic importance.

After oil was discovered on the shores of the Beaufort Sea in northern

The Exxon Valdez Oil Spill

On March 24, 1989, the tanker *Exxon Valdez*, with a cargo of fifty-three million gallons of crude oil, ran aground on Bligh Reef in Prince William Sound, Alaska. Approximately eleven million gallons of oil were released into the water, in one of the worst environmental disasters of this type recorded to date. Despite immediate and lengthy efforts to contain and clean up the spill, there was extensive damage to wildlife, including aquatic birds, seals, and fish. Lawsuits and calls for new regulatory legislation on tankers continued a decade later. Such regrettable incidents as these are the almost inevitable result of attempting to transport the huge oil supplies demanded in the industrialized world.

A section of the Alaska Pipeline, which carries crude oil from the state's northern slopes to Valdez on Alaska's southern coast. (PhotoDisc)

Alaska (the so-called North Slope) in the 1960's, a pipeline was built across Alaska, ending at the port of Valdez. The pipeline is heated to keep the oil liquid in cold weather and elevated to prevent its melting through the permanently frozen ground (permafrost) that supports it. From Valdez, tankers reach Japan or California.

Drilling activities occasionally result in discovery of natural gas, which is valued as a low-pollution fuel. Vast fields of gas exist in Siberia, and gas is piped to Western Europe through a pipeline. Algerian gas is shipped in the liquid state in ships equipped with refrigeration equipment to maintain the low temperatures needed. Late 1990's gas finds in Alberta, Canada, were expected to help supply the energy needs of the central United States when a pipeline is built. Britain and Northern Europe also benefit from gas produced in the North Sea, between Norway and Scotland.

Shale oil, a plentiful but difficult-to- exploit fossil fuel, exists in enormous amounts near Rifle, Colorado. A form of oil-bearing rock, the shale must be crushed and heated to recover the oil, a more expensive proposition than drilling conventional oil wells. In spite of ingenious schemes such as burning the shale oil in place, this resource is likely to remain largely unused until conventional petroleum is used up. A similar resource exists in Alberta, Canada, where the Athabasca tar sands are exploited for heavy oils.

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Manufacturing

Manufacturing is the process by which value is added to materials by changing their physical form—shape, function, or composition. For example, an automobile is manufactured by piecing together thousands of different component parts, such as seats, bumpers, and tires. The component parts in unassembled form have little or no utility, but pieced together to produce a fully functional automobile, the resulting product has significant utility. The more utility something has, the greater its value. In other words, the value of the component parts increases when they are combined with the other parts to produce a useful product.

Employment in Manufacturing. On a global scale, only 20 percent of the world's working population had jobs in the manufacturing sector at the end of the twentieth century. The rest worked in agriculture and mining (49 percent) and services (31 percent). The importance of each of these sectors varies from country to country and from time period to time period. High-income countries have a higher percentage of their labor force employed in manufacturing than low-income countries do. For example, in the United States 18 percent of the labor force worked in manufacturing in the late 1990's, whereas the African country of Tanzania had only 5 percent of its labor force employed in the manufacturing sector at that time.

At the end of the twentieth century, the vast majority of the U.S. labor force (81 percent) worked in services, a sector that includes jobs such as computer programmers, lawyers, and teachers. Only 1 percent worked in agriculture and mining. This employment structure is typical for a high-income country. In low-income countries, in contrast, the majority of the labor force have agricultural jobs. In Tanzania, for example, 84 percent of the labor force worked in agriculture, while services accounted for 11 percent of the jobs.

The importance of manufacturing changes over time. In 1950 manufacturing accounted for 38 percent of all jobs in the United States. The percentage of jobs accounted for by the manufacturing sector in high-income countries has decreased in the post-World War II period. The decreasing share of manufacturing jobs in high-income countries is partly attributable to the fact that many manufacturing companies have replaced people with machines on assembly lines. Because one machine can do the work of many people, manufacturing has become less labor-intensive (uses fewer people to perform a particular task) and more capital-intensive (uses machines to perform tasks formerly done by people). In the future, manufacturing in high-income countries is expected to become increasingly capital-intensive. It is not inconceivable that manufacturing's share of the U.S. labor force could fall below 10 percent in the twenty-first century.

Although the importance of manufacturing as an employer is decreasing, it should be noted that manufacturing jobs tend to pay higher wages than jobs in many other sectors. For example, the average manufacturing job in the United States paid more than $35,000 per year, while the average construction job paid just over $31,000 and the average retail job just over $20,000.

Geography of Manufacturing. Every country produces manufactured goods, but the vast bulk of manufacturing activity is concentrated geographically in three major manufacturing regions—eastern North America, Europe, and eastern Asia. Together, these three regions produce more than 85 percent of the world's manufacturing output. In fact, three countries—the United States, Japan, and Germany—produce almost 60 percent of the world's manufactured goods. The concentration of manufacturing activity in a small number of regions means that there are other regions where very little manufacturing occurs. Africa is a prime example of a region with little manufacturing.

Different countries tend to specialize in the production of different products. For example, 50 percent of the automobiles that were produced in that late 1990's were produced in three countries—Germany, Japan, and the United States. In the production of television sets, the top three countries were China, Japan, and South Korea, which together produced 48 percent of the world's television sets. It is important to note that these patterns change over time. For example, in 1960 the top three automobile-producing countries were Germany, the United Kingdom, and the United States, which together produced 76 percent of the world's automobiles.

Multinational Corporations. A multinational corporation is a corporation that is headquartered in one country but owns business facilities, for example, manufacturing plants, in other countries. Some examples of multinational corporations from the manufacturing sector include the automobile maker Ford, whose headquarters are the in the United States, the pharmaceutical company Bayer, whose headquarters are in Germany, and the candy manufacturer Nestle, whose headquarters are in Switzerland. Since the end of World War II, multinational corporations have become increasingly important in the world economy. Most multinational corporations have headquarters in high-income countries.

Companies open manufacturing plants in other countries for a variety of reasons. One of the most common reasons is that it allows them to circumvent barriers to trade that are imposed by foreign governments, especially tariffs and quotas. A tariff is an import tax that is imposed upon foreign-manufactured goods as they enter a country. A quota is a limitation imposed on the volume of a particular good that a particular country can export to another country. The net effect of tariffs and quotas is to increase the cost of imported goods for consumers.

Governments impose tariffs and quotas partly to raise revenue and partly to encourage consumers to purchase goods manufactured in their own country. Foreign manufacturers faced with tariffs and quotas often begin manufacturing their product in the country imposing the tariffs and quotas. As tariffs and quotas apply to imported goods only, producing in the country imposing the quotas or tariffs effectively makes these trade barriers obsolete.

Companies also open manufacturing plants in other countries because of differences in labor costs among countries. While most manufacturing takes place in high-income countries, some low-income countries have become increasingly attractive as production locations because their workers can be hired much more cheaply than in high-income countries. For example, in the late 1990's, the average manufacturing job in the United States paid more than $17 per hour. By comparison, manufacturing employees in the Asian country of Sri Lanka earned less than $1 per hour.

This dramatic differences in labor costs have prompted some companies to close down their manufacturing plants in high-income countries and open up new plants in low-income countries. This has resulted in high-income countries purchasing more manufactured goods from low-income countries. In 1988, for example, 28 percent of the clothing purchased by U.S. consumers was imported from other countries, while in 1998, 48 percent of the clothing purchased in the United States was imported.

More than half the clothing imported into the United States came from Asian countries, for example, China, Taiwan, and South Korea, where labor costs were much lower than in the United States. Much of this clothing was made in factories where workers were paid by companies headquartered in the United States. For example, most of the Nike sports shoes that were sold in the United States were made in China, Indonesia, Vietnam, and Pakistan.

Transportation and Communications Technology. The ability of companies to have manufacturing plants in other countries stems from the fact that the world has a sophisticated and efficient transportation and communications system. An advanced transportation and communications system makes it relatively easy and relatively cheap to transfer information and goods between geographically distant locations. Thus, Nike can manufacture soccer balls in Pakistan and transport them quickly and cheaply to customers in the United States.

The extent to which transportation and communications systems have improved during the last two centuries can be illustrated by a few simple examples. In 1800, when the stagecoach was the primary method of overland transportation, it took twenty hours to travel the ninety miles from Lansing, Michigan, to Detroit, Michigan. Today, with the automobile, the same journey takes approximately ninety minutes. In 1800 sailing ships traveling at an average speed of ten miles per hour were used to transport people and goods between geographically distant countries. In the year 2000 jet-engine aircraft could traverse the globe at speeds in excess of six hundred miles per hour.

Communications technology has also improved over time. In 1930 a three-minute telephone call between New York and London, England, cost more than $250 in 1998 dollars. In the year 2000 the same telephone call could be made for less than a dollar. In addition to modern telephones, there are fax machines, e-mail, video conferencing capabilities, and a host of other technologies that make communication with other parts of the world both inexpensive and swift

Future Prospects. The global economy of the twenty-first century presents a wide variety of opportunities and challenges. Sophisticated communications and transportation networks provide increasing numbers of manufacturing companies with more choices as to where to locate their factories. However, high-income countries like the United States are increasingly in competition with other countries (both high- and low-income) to maintain existing manufacturing investments and attract new ones. Persuading existing companies to keep their U.S. factories open and not move overseas has been a major challenge. Likewise, making the United States an attractive place for foreign companies to locate their manufacturing plants is an equally challenging task.

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Globalization of Manufacturing and Trade

Why are most of the patents issued worldwide assigned to U.S. corporations? How did a Taiwanese earthquake prevent millions of Americans from purchasing memory upgrades for their computers? Why have personal incomes in Beijing nearly doubled in less than a decade?

Answers to these questions can be found in the geography of globalization. Globalization is an economic, political, and social process characterized by the integration of the world's many systems of manufacturing and trade into a single and increasingly seamless marketplace. The result: a new world geography.

This new geography is associated with the expansion of manufacturing and trade as capitalist principles replace old ideologies and state-controlled economies. With expanded free markets, the process of manufacturing and trading is constantly changing. Globalization delivers economic growth through improved manufacturing processes, newly developed goods, foreign investment in overseas manufacturing, and expanded employment.

The economies of developing countries are slowly transitioning from agricultural to industrial activities. Nevertheless, more than 70 percent of workers in these countries continue to work in agriculture. Meanwhile, developed countries, such as Australia and Germany, are experiencing high-technology service sector growth and reduced manufacturing employment. In the United States, nearly 50 percent of all workers were employed in manufacturing during the 1950's, but by the late 1990's, less than 20 percent were.

In between these extremes, former state-controlled economies, like Romania, are adopting more efficient economic development strategies. Other nations and economic models, such as Indonesia and China, are pulled into the global marketplace by the growth and expansion of market economies. Despite the different economic paths of developing, transitioning, and developed nations, manufacturing and trade link all nations together and represent an economic convergence with important implications for political, business, and labor leaders—as well as all the world's citizens.

The geographies of manufacturing and trade can be examined as the distribution and location of economic activities in response to technological change and political and economic change.

Distribution and Location. Questions about where people live, work, and spend their money can be answered by reading product labels in any shopping mall, supermarket, or automobile dealership. They reveal the fact that manufacturing is a multistage process of component fabrication and final product assembly that can occur continents apart. For example, a shirt may be designed in New Jersey, assembled in Costa Rica from North Carolina fabric, and sold in British Columbia. To understand how goods produced in far-away locations are sold at neighborhood stores, geographers investigate the spatial, or geographic, distribution of natural resources, manufacturing plants, trading patterns, and consumption.

Historically, the geography of manufacturing and trade has been closely linked to the distribution of raw materials, workers, and buyers. In earlier times, this meant that manufacturing and trade were highly localized functions. In the eighteenth century, every North American town had cobblers or blacksmiths who produced goods from local resources for sale in local markets. By the start of the Industrial Revolution, improved transportation and manufacturing techniques had significantly enlarged the geography of manufacturing and trade. As distances increased, new manufacturing and trading centers developed. The location of these centers was contingent upon site and situation. Site and situation refer to a physical location, or site, relative to needed materials, transportation networks, and markets. For example, Pittsburgh, Pennsylvania, became the site of a major steel industry because it was near coal and iron resources. Pittsburgh also benefited from its historical role as a port town on a major river system that provided access to both western and eastern markets.

While relative location and transportation costs continue to be important factors, the geographic distribution of production and movement of goods across space is more complex than the simple calculus of site and situation. New global and local geographies of manufacturing and trade have been fueled by two major factors: technology and political change.

Technological Change. The old saying that time is money partially explains where goods are manufactured and traded. By compressing time and space, technology has enabled people, goods, and information to go farther more quickly. In the process, technology has reduced interaction costs, such as telecommunications. Just as steel enabled railroads to push farther westward, new technologies reduce the distance between places and people.

By increasing physical and virtual access to people, places, and things, technology has eliminated many barriers to global trade. However, improved telecommunications and transportation are only part of technology's contribution to globalization. If time is money, new efficient manufacturing processes also have reduced costs and facilitated globalization.

Armed with more efficient production processes, reliable telecommunications infrastructures, and transportation improvements, businesses can increase profits and remain competitive by seeking out lower-cost labor markets thousands of miles from consumers. As trade and manufacturing are increasingly spatially separate activities, the geographic distribution of manufacturing promotes an uneven distribution of income. The global distribution of manufacturing plants is closely related to industry-specific skill and wage requirements. For example, low-wage and low-skill jobs tend to concentrate in the developing regions of Asia, South America, and Africa. Alternately, high-technology and high-wage manufacturing activities concentrate in more developed regions.

In some cases, high wages and global competition force corporations to move their manufacturing plants to save costs and remain competitive. During the early 1990's, this byproduct of globalization was a major issue during the U.S. and Canadian debates to ratify the North American Free Trade Agreement (NAFTA). Focusing on primarily U.S. and Canadian companies that moved jobs to Mexico, the debate contributed to growing anxiety over job security as plants relocate to low-cost labor markets in South America and around the world.

As global competition increases, the geography of manufacturing and trade is increasingly global and rapidly changing. One company that has adapted to the shifting nature of global trade and manufacturing is Nike. Based in Beaverton, Oregon, Nike designs and develops new products at its Oregon world headquarters. However, Nike has internationalized

The World Trade Organization and Global Trading

In 1998 domestic political pressures and an expected domestic surplus of rice prompted the Japanese government to unilaterally implement a 355 percent tariff on foreign rice, violating the United Nations' General Agreement on Tariffs and Trade (GATT). On April 1, 1999, Japan agreed to return to GATT import levels and imposed new over-quota tariffs. While domestic Japanese politics could have prompted a trade war with rice-exporting countries, the crisis demonstrates how multilateral trading initiatives promote stability. Without an agreement, rice exporters might not have gained access to Japanese markets. By returning to GATT minimum quotas and implementing over-quota taxes, the compromise addressed the interests of both domestic and foreign rice growers.

much of its manufacturing capacity to compete in an aggressive athletic apparel industry. Over the last twenty-five years, Nike's strategy has meant shifts in production from high-wage U.S. locations to numerous low-wage labor markets around Pacific Rim.

Political and Economic Change: A New World Order. In order for companies such as Nike to successfully adapt to changing global dynamics, a stable international, or multilateral, trading system must be in place. In 1948 the General Agreement on Tariffs and Trade (GATT) was the first major step toward developing this stable global trading infrastructure. During that same period, the World Bank and International Monetary Fund were created to stabilize and standardize financial markets and practices. However, Cold War politics postponed complete economic integration for nearly half a century. Since the collapse of communism, globalization has accelerated as economies coalesce around the principles of free markets and capitalism. These important changes have become institutionalized through multilateral trade agreements and international trading organizations.

International trading organizations try to minimize or eliminate barriers to free and fair trade between nations. Trade barriers include tariffs (taxes levied on imported goods), product quotas, government subsidies to domestic industry, domestic content rules, and other regulations. Barriers prevent competitive access to domestic markets by artificially raising the prices of imported goods too high or preventing foreign firms from achieving economies of scale. In some cases, tariffs can also be used to promote fair trade by effectively leveling the playing field.

Because tariffs can be used both to promote fair trade and to unfairly protect markets, trading organizations are responsible for distinguishing between the two. For example, the Asian Pacific Economic Cooperation (APEC) forum has established guidelines to promote fair trade and attract foreign investment. APEC initiatives include a public Web-based database of member state tariff schedules and related links. Through programs such as the APEC information-sharing project, trading organizations are streamlining the international business process and promoting the overall stability of international markets.

The Future. As the globalization of manufacturing and trade continues, a new world geography is emerging. Unlike the Cold War's east-west geography and politics of ideology, an economic politics divides the developed and developing world along a north-south axis. While the types of conflicts associated with these new politics and the rules of engagement are unclear, it is evident that a new hierarchy of nations is emerging.

Globalization will raise the economic standard of living in most nations, but it has also widened the gap between richer and poorer countries. A small group of nations generates and controls most of the world's wealth. Conversely, the poorest countries account for roughly two-thirds of the world's population and less than 10 percent of its wealth.

This fundamental question of economic justice was a motive behind globalization's first major political clash. During the 1999 World Trade Organization (WTO) meetings in Seattle, Washington, approximately fifty thousand environmentalists, labor unionists, and human and animal rights activists protested against numerous issues, including cultural intolerance, economic injustice, environmental degradation, political repression, and unfair labor practices they attribute to free trade. While the protesters managed to cancel the opening ceremonies, the United Nations secretary-general, Kofi Annan, expressed the general sentiment of most WTO member states. Agreeing that the protesters' concerns were important, Annan also asserted that the globalization of manufacturing and trade should not be used as a scapegoat for domestic failures to protect individual rights. More important, the secretary-general feared that those issues could be little more than a pretext for a return to unilateral trade policies, or protectionism.

Like the Seattle protesters, supporters of multilateral trade advocate political and economic reforms. Proponents emphasize that open markets promote open societies. Free traders earnestly believe economic engagement encourages rogue nations to improve poor human rights, environmental, and labor records. It is argued that economic engagement raises the expectations of citizens, thereby promoting change. This phenomenon has been partially credited with the fall of the Berlin Wall. It remains to be seen if free trade equals freedom in all places and under all circumstances, and globalization continues to be controversial.

Conclusion. Technological and political change have made global labor and consumer markets more accessible and established an economic world hierarchy. At the top, one-fifth of the world's population consumes the vast majority of produced goods and controls more than 80 percent of the wealth. At the bottom of this hierarchy, poor nations are industrializing but possess less than 10 percent of the world's wealth. In political, social, and cultural terms, this global economic reality defines the contours and cleavages of a changing world geography. Whether geographers calculate the economic and political costs of a widening gap between rich and poor or chart the flow of funds from Tokyo to Toronto, the globalization of manufacturing and trade will remain central to the study of geography well into the twenty-first century.

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Information on the World Wide Web

The Web site of the World Trade Organization (WTO) details the history of the organization and free trade as well as the implications of global trading. (www.wto.org)

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Modern World Trade Patterns

Trade, its routes, and its patterns are an integral part of modern society. Trade is primarily based on need. People trade the goods that they have, including money, to obtain the goods that they don't have. Some nations are very rich in agriculture or natural resources, while others are centers of industrial or technical activity. Because nations' needs change only slowly, trade routes and trading patterns develop that last for long periods of time.

Types of Trade. The movement of goods can occur among neighboring countries, such as the United States and Mexico, or across the globe, as between Japan and Italy. Some trade routes are well established with regularly scheduled service connecting points. Such service is called liner service. Liners may also serve intermediate points along a trade route to increase their revenue.

Some trade occurs only seasonally, such as the movement of fresh fruits from Chile to California. Some trade occurs only when certain goods are demanded, such as special orders of industrial goods. This type of service is provided by operators called tramps. They go where the business of trade takes them, rather than along fixed liner schedules and routes.

Many people think of international trade as being carried on great ships plying the oceans of the world. Such trade is important; however, a considerable amount of trade is carried by other modes of transportation. Ships and airplanes carry large volumes of freight over large distances, while trucks, trains, barges, and even animal transport are used to move goods over trade routes among neighboring or landlocked countries.

Trade Routes. Through much of human history, trade routes were limited. Shipping trade carried on sailing vessels, for example, was limited by the prevailing winds that powered the ships. Land routes were limited by the location of water, mountain ranges, and the slow development of roads through thick forests and difficult terrain. The mechanization of transportation eventually freed ships and other forms of transport to follow more direct trade routes. Also, the development of canals and transcontinental highway systems allowed trade routes to develop based solely upon economic requirements.

Other changes in trade routes have occurred with industrialization of transport systems. The world began to have a great need for coal. Trade routes ran to the countries in which coal was mined. Ships and trains delivered coal to the power industry worldwide. Later, trade shifted to locations where oil (petroleum) was drilled. Now, oil is delivered to those same powerplants and industrial sites around the world.

Noneconomic Factors. Some trade is not purely economic in nature. Political relationships among countries can play an important part in their trade relations. For example, many national governments try to protect their countries' automobile and electronics industries from outside competition by not allowing foreign goods to be imported easily. Governments control imports by assessing duties, or tariffs, on selected imports.

Some national governments use the concept of cabotage to protect their home transportation industries by requiring that certain percentages of imported and exported trade goods be carried by their own carriers. For example, the U.S. government might require that 50 percent of its trade use American ships, planes or trucks. The government might also require that all American carriers employ only American citizens.

Nations also can exert pressure on their trading partners by limiting access to port or airport facilities. Stronger nations may force weaker nations into accepting unequal trade agreements. For example, the United States once had an agreement with Germany concerning air passenger service between the two countries. The agreement allowed United States carriers to carry 80 percent of the passengers, while German carriers were permitted to carry only 20 percent of the passengers.

Multilateral Trade. In situations in which pairs of trading nations do not have direct diplomatic contact with each other, they make their trade arrangements through other nations. Such trade is referred to as multilateral. Certain carriers cater to this type of trade. They operate their ships or planes in around-the-world service. They literally travel around the globe picking up and depositing cargo along the way for a variety of nations.

Trade Patterns. For many years, world populations were coast centered. This means that most of the people in the country lived close to the coast. This was due primarily to the availability of water transportation systems to move both goods and people. At this time, major railroad, highway and airline systems did not exist. As railroad and highway systems pushed into the interiors of nations, the population followed, and goods were needed as well as produced in these areas. Thus, over the years many inland population centers have developed that require transportation systems to move goods into and away from this area.

In these cases, international trade to these inland centers required the use of a number of different modes of transportation. Each of the different modes required additional paperwork and time for repackaging and securing of the cargo. For example, cargo coming off ships from overseas was unloaded and placed in warehouse storage. At some later time, it was loaded onto trucks that carried it to railyards. There it would be unloaded, stored, and then loaded onto railcars. At the destination, the cargo would once again be shifted to trucks for the final delivery. During the course of the trip, the cargo would have been handled a number of times, with the possibility of damage or loss occurring each time.

Containerization. As more goods began to move in international trade, the systems for packaging and securing of cargo became more standardized. In the 1960's, shipments began to move in containers. These are highway truck trailers which have been removed from the chassis leaving only the box. Container packaging has become the standard for most cargos moving today in both domestic and international trade. With the advent of containerization of cargo in international trade, cargo movements could quickly move intermodally. Intermodal shipping involves the movement of cargo by using more than a single mode of transportation.

Land, water, and air carriers have attempted to make the intermodal movement of cargo in international trade as seamless as possible. They

Crane lifting cargo containers at an Asian shipyard. (PhotoDisc) have not only standardized the box for carrying cargo, but they have also standardized the handling equipment, so that containers move quickly from one mode to another. Advances in communications and electronic banking allow the paperwork and payments also to be completed and transferred rapidly.

As the demands for products have grown and as the size of industrial plants has grown, the size of movements of raw materials and containerized cargo has also grown. Thus, the sizes of the ships and trains required to move these large volumes of cargo have also increased.

The development of VLCC's (very large crude carriers) has allowed shippers to move large volumes of oil products. The development of large bulk carriers has allowed for the carriage of large volumes of dry raw materials such as grains or iron ore. These large vessels take advantage of what is known as economies of scale. Goods can moved more cheaply when large volumes of them are moved at the same time. This is because the doubling of the volume of cargo moved does not double the cost to build or operate the vessels in which it is carried. This savings reduces the cost to move large volumes of cargo.

Intermodal Transportation. Intermodal transportation has allowed cargo to move seamlessly across both international boundaries and through different modes of transportation. This seamless movement has changed ocean trade routes over recent years.

The development of the Pacific Rim nations created a demand for trade between East Asia and both the United States and Europe. This trade has usually taken the all-water routes between Asia and Europe. Ships moving from East Asia across the Pacific Ocean pass through the Panama Canal and cross the Atlantic Ocean to reach Western Europe. This journey is in excess of 10,000 miles (16,000 km.) and usually takes about thirty days for most ships to complete. The all-water route from Asia to New York is similar. The distance is almost as great as that to Europe and requires about twenty-one to twenty-four days to complete.

Intermodal transportation has given shippers alternatives to all-water routes. A great volume of Asian goods is now shipped to such western U.S. ports as Seattle, Oakland, and Los Angeles, from which these goods are carried by trains across the United States to New York. The overall lengths of these routes to New York are only about 7,400 miles (12,000 km.) and take between fifteen and nineteen days to complete. Cargos continuing to Europe are put back on ships in New York and complete their journeys in an additional seven to ten days. Such intermodal shipping can save as much as a week in delivery time.

Airfreight. Another changing trend in trade patterns is the development of airfreight as an international competitor. Modern aircraft have improved dramatically both in their ability to lift large weights of cargo as well as their ability to carry cargos over long distances. Because of the speed at which aircraft travel in comparison to other modes of transportation, goods can be moved quickly over large distances. Thus, high-value cargos or very fragile cargos can move very quickly by aircraft.

The drawback to airfreight movement of cargo is that it is more expensive than other modes of travel. However, for businesses that need to move perishable commodities, such as flowers of the Netherlands, or expensive commodities, such as Paris fashions or Singapore-made computer chips, airfreight has become both economic and essential.

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Political Geography

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Forms of Government

Philosophers and political scientists have studied forms of government for many centuries. Ancient Greek philosophers such as Plato and Aristotle wrote about what they believed to be good and bad forms of government. According to Plato's famous work, *The Republic*, the best form of government was one ruled by philosopher-kings. Aristotle wrote that good governments, whether headed by one person (a kingship), a few people (an aristocracy), or many people (a polity), were those that ruled for the benefit of all. Those that were based on narrow, selfish interests were considered bad forms of government, whether ruled by an individual (a tyranny), a few people (an oligarchy), or many people (a democracy). Thus, democracy was not always considered a good form of government.

Constitutions and Political Institutions. All governments have certain things in common: institutions that carry out legislative, executive, and judicial functions. How these institutions are supposed to function is usually spelled out in a country's constitution, which is a guide to organizing a country's political system. Most, but not all, countries have written constitutions. Great Britain, for example, has an unwritten constitution based on documents such as the Magna Carta, the English Bill of Rights, and the Treaty of Rome and on unwritten codes of behavior expected of politicians and members of the royal family.

The world's oldest written constitution still in use is that of the United States. All countries have written or unwritten constitutions, and most follow them most of the time. Some countries do not follow their constitu-

Greek philosopher Aristotle, who lived in the fourth century B.C.E., laid down some of the earliest recorded principles of government. (Library of Congress) tions—for example, the Soviet Union did not; other countries, for example France, change their constitutions frequently.

Constitutions usually first specify if the country is to be a monarchy or a republic. Few countries still have monarchies, and those that do usually grant the monarch only ceremonial powers and duties. Countries with monarchies at the beginning of the twenty-first century included Spain, Great Britain, Lesotho, Swaziland, Sweden, Saudi Arabia, and Jordan. Most countries that do not have monarchies are republics.

Constitutions also specify if power is to be concentrated in the hands of a strong national government, which is a unitary system; if it is to be divided between a national and various subnational governments such as states, provinces, or territories, which is a federal system; or if it is to be spread among various subnational governments that might delegate some power to a weak national government, which is a confederate system.

Examples of countries with unitary systems include Great Britain, France, and China; federal systems include the United States, Germany, Russia, Canada, India, and Brazil. There were no confederate systems in the late 1990's, although there are examples from history. The United States under its eighteenth-century Articles of Confederation and the nineteenth-century Confederate States of America, made up of the rebelling Southern states, were confederate systems. Switzerland was a confederation for much of the nineteenth century. The concept of dividing power between the national and subnational governments is called the vertical axis of power.

Whether governments share power with subnational governments or not, there must be institutions to make laws, enforce laws, and interpret laws: the legislative, executive, and judicial branches of government. How these branches interact is what determines whether governments are parliamentary, presidential, or mixed parliamentary-presidential. In a presidential system, such as in the United States, the three branches—legislative, executive, and judicial—are separate, independent, and designed to check and balance each other according to a constitution. In a parliamentary system, the three branches are not entirely separate, and the legislative branch is much more powerful than the executive and judicial branches.

Great Britain is a good example of a parliamentary system. Some countries, such as France and Russia, have created a mixed parliamentary-presidential system, wherein the three branches are separate but are not designed to check and balance each other. In a mixed parliamentary-presidential system, the executive (led by a president) is the most powerful branch of government.

Looking at political systems in this way—how the legislative, executive, and judicial branches of government interact—is to examine the horizontal axis of power. All governments are unitary, federal, or confederate, and all are parliamentary, presidential, or mixed parliamentary-presidential. One

Monarchies of the World

Country	*Monarch*	*Type of monarchy*
Australia	Queen Elizabeth II	Constitutional
Bahrain	Sheikh Hamad ibn ‘Isa Al Khalifah	Traditional
Belgium	King Albert II	Constitutional
Bhutan	King Jigme Singye Wangchuk	Constitutional
Brunei	Sultan Haji Hassanal Bolkiah	Constitutional
Cambodia	King Norodom Sihanouk	Constitutional
Canada	Queen Elizabeth II	Constitutional
Denmark	Queen Margrethe II	Constitutional
Japan	Emperor Akihito	Constitutional
Jordan	King Abdullah II	Constitutional
Kuwait	Sheik Jaber al-Ahmad al-Sabah	Constitutional
Lesotho	King Letsie III	Constitutional
Liechtenstein	Prince Hans Adam II	Constitutional
Luxembourg	Grand Duke Henri	Constitutional
Malaysia	Syed Sirajuddin	Constitutional
Monaco	Prince Rainier III	Constitutional principality
Morocco	King Muhammad VI	Constitutional
Nepal	King Gyanendra	Constitutional
Netherlands	Queen Beatrix	Constitutional
New Zealand	Queen Elizabeth II	Constitutional
Norway	King Harald V	Constitutional
Oman	Sultan Qabus ibn Sa’id	Absolute
Qatar	Emir Sheikh Hamad ibn Khalifah Al Thani	Traditional
Saudi Arabia	King Fahd bin ‘Abdulaziz	Absolute
Spain	King Juan Carlos I	Parliamentary
Swaziland	King Mswati III	Near-absolute
Sweden	King Carl XVI Gustaf	Constitutional
Thailand	King Phumiphon Adunyadet	Constitutional
Tonga	King Taufa’ahau Tupou IV	Constitutional
United Kingdom	Elizabeth II	Constitutional

can find examples of different combinations. Great Britain is unitary and parliamentary. Germany is federal and parliamentary. The United States is federal and presidential. France is unitary and mixed parliamentary-presidential. Russia is federal and mixed parliamentary-presidential. Furthermore, virtually all countries are either republics or monarchies.

Types of Government. Constitutions describe how the country’s political institutions are supposed to interact and provide a guide to the relationship between the government and its citizens. Thus, while governments may have similar political institutions—for example, Germany and India are both federal, parliamentary republics—how the leaders treat their citizens can vary widely. However, governments may have political systems that function similarly although they have different forms of constitutions and institutions. For example, Great Britain, a unitary, parliamentary monarchy with an unwritten constitution, treats its citizens very similarly to the United States, which is a federal, presidential republic with a written constitution.

The three most common terms used to describe the relationships between those who govern and those who are governed are democratic, authoritarian, and totalitarian. Characteristics of democracies are free, fair, and meaningfully contested elections; majority rule and respect for minority rights and opinions; a willingness to hand power to the opposition after an election; the rule of law; and civil rights and liberties, including freedom of speech and press, freedom of association, and freedom to travel. The United States, Canada, Japan, and most European countries are democratic.

An authoritarian system is one that curtails some or all of the characteristics of a democratic regime. For example, authoritarian regimes might permit token electoral opposition by allowing other political parties to run in elections, but they do not allow the opposition to win those elections. If the opposition did win, the authoritarian regime would not hand over power. Authoritarian regimes do not respect the rule of law, the rights of minorities to dissent, or freedom of the press, speech, or association. Authoritarian governments use the police, courts, prisons, and the military to intimidate and threaten their citizens, thus preventing people from uniting to challenge the existing political rulers. Cuba, Mexico, Peru, Libya, Serbia, Belarus, and China are examples of countries with authoritarian regimes.

Totalitarian regimes are similar to authoritarian regimes but are even more extreme. Under a totalitarian regime, there is no legal opposition, no freedom of speech, and no rule of law whatsoever. Totalitarian regimes attempt to control totally all members of the society to the point where everyone always must actively demonstrate their loyalty to and support for the regime. Nazi Germany under Adolf Hitler's rule (1933-1945) and the Soviet Union under Joseph Stalin's rule (1928-1953) are examples of totalitarian regimes.

Forms of Government: Putting it All Together. In *The Republic*, Plato asserts that people have varied dispositions, and, therefore, there are various types of governments. In recent years, regimes have been created that some call mafiacracies (rule by criminal mafias), narcocracies (rule by narcotics gangs), gerontocracies (rule by very old people), theocracies (rule by religious leaders), and so forth. Such variations show the ingenuity of the human mind in devising forms of government.

Whatever labels that are given to a political system, there are several basic questions to be asked about that regime: Is it a monarchy or a republic? Is all power concentrated in the hands of a national government, or is power shared between a national government and the states or provinces? Are its institutions those of a parliamentary, presidential, or mixed parliamentary-presidential system? Is it democratic, authoritarian, or totalitarian? Finally, does it live up to its constitution, both in terms of how power is supposed to be distributed among institutions and in its relationship between the government and the people? To paraphrase Aristotle, how many rulers are there, and in whose interests do they rule?

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Political Geography

Students of politics have been aware that there is a significant relationship between physical and political geography since the time of ancient Greece. The ancient Greek philosopher Plato argued that a *polis* (politically organized society) must be of limited geographical size and limited population or it would lack cohesion. The ideal *polis* would be only as geographically large as required to feed about five thousand people, its maximum population.

Plato's illustrious pupil, Aristotle, agreed that stable states must be small. "One can build a wall around the Hellespont," the main territory of ancient Greece, he wrote in his treatise *Politics,* "but that will not make it a polis." Today human ideas differ about the maximum area of a successful state or nation-state, but the close influence of physical geography on political geography and their profound mutual effects on politics itself are not in question.

Geographical Influences on Politics. The physical shape and contours of states may be called their physical geography; the political shape and contours of states, starting with their basic structure as unified state, federation, or confederation, are primary features of their political geography. The idea of "political geography" also can refer to variations in a population's political attitudes and behavior that are influenced by geographical features. Thus, the combination of plentiful land and sparse population tend toward an independent spirit, especially where the economy is agriculturally based. This has historically been the case in the western United States; in the Pampas region of Argentina, where cattle are raised by independent-mined gauchos (cowboys); and on the Brazilian frontier, where government regulation is routinely resisted.

Likewise, where physical geography presents significant difficulties for inhabitants in earning a living or associating, as where there is rough terrain and poor soil or inhospitable climate, the populace is likely to exhibit a hardy, self-reliant character that strongly influences political preferences. Thus, physical geography helps to shape national character, including aspects of a nation's politics.

Furthermore, it is well known that where physical geography isolates one part of a country's population from the rest, political radicalism may take root. This tendency is found in coastal cities and remote regions, where labor union radicalism has often been pronounced. Populations in coastal locations with access to foreign trade often show a more liberal, tolerant, and outgoing spirit, as reflected in their political opinions. In ancient Greece, the coastal access enjoyed by Athens through a nearby port in the fifth century B.C.E. had a strong influence on its liberal and democratic political order. In modern times, China's coastal cities, such as Tientsin, and North American cities such as San Francisco, show similar influences.

The Geographical Imperative. In many instances, political geography is shaped by what may be called the "geographical imperative." Physical geography in these instances demands, or at least strongly suggests, that political geography follow its course. The numerous valleys of mountainous Greece strongly influenced the emergence of the small, often fiercely independent, polis of ancient times. The formation and borders of Asian states such as Bhutan, Nepal, and Tibet have been strongly influenced by the Himalaya Mountains, and the Alps shape Switzerland.

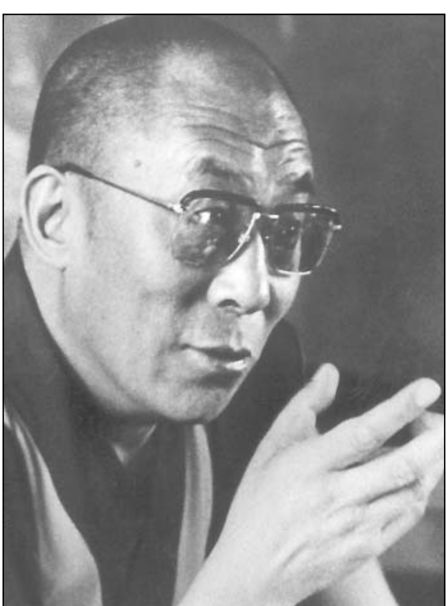
As another example, physical geography demands that the land between the Pacific Ocean and the Andes Mountains along the western edge of South America be organized as a separate country—Chile. Island geography often plays a decisive role in its political geography. The qualified political unity of Great Britain can be directly traced to its insular status. Small islands often find themselves combined into larger units, such as the Hawaiian Islands.

The absence of the geographical imperative, however, leaves political geography an open question. For example, Indonesia comprises some thirteen hundred islands stretching three thousand miles in bodies of water such as the Indian Ocean and the Celebes Sea. With so many islands, Indonesia lacks a geographical imperative to be a unified state. It also lacks the imperative of ethnic and cultural homogeneity and cohesion, a circumstance mirrored in its political life, since it has remained unified only through military force. As control by the military waned after the fall of the authoritarian General Suharto in 1998, conflicts among the nation's diverse peoples have threatened its breakup. No such threat, however, confronts Australia, an immense island continent where a European majority dominates a fragmented aboriginal minority. In Australia, the geographical imperative suggests a unity supported by the cultural unity of the majority.

As many examples show, the geographical imperative is not absolute. For example, mountainous Greece is politically united in the twentieth century. Although long shielded geographically, Tibet lost its political independence after it was successfully invaded by China. The formerly independent Himalayan state Sikkim was taken over by India. Thus, political will trumps physical geography.

The frequency of exceptions to the geographical imperative illustrates that human freedom, while not unlimited, often plays a key role in shaping political geography. As one example, the Baltic Republics of Lithuania, Latvia, and Estonia historically have been dominated, or largely swallowed up, by neighboring Russia. At the start of the twenty-first century, however, they had regained their independence through the political will to self-rule and the drive for cultural survival.

Strategically Significant Locations. Locations of great economic or military significance become focal points of political attention and, potentially, of military conflict. There are innumerable such places in the



Tenzin Gyatso, the Dalai Lama, is the secular and ecclesiastical ruler of Tibet. In 1950 he went into exile to protest China's violent occupation of Tibet. (©The Nobel Foundation) world, but several stand out as models of how important physical geography can be for political geography in the context of international politics.

One significant example is the Panama Canal, without which ships must sail around South America. The Suez Canal, which connects European and Asian shipping, is a similar waterway, saving passage around Africa. The canal's significance was reduced after 1956, however, when its blockage after the Arab-Israeli war of that year led to the building of supertankers too large to traverse it. Another example is Gibraltar, whose fortifications command the entrance to the Mediterranean Sea from the Atlantic Ocean. A final example is the Bosporus, the tiny entrance from the Black Sea to waters leading to the Mediterranean Sea. It is the only warm-water route to and from Eastern Russia and therefore is of great military and economic importance for regional and world power politics.

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Geopolitics

Geopolitics is a concept pertaining to the role of purely geographical features in the relations among states in international politics. Geopolitics is especially concerned with the geographical locations of the states in relationship to one another. Geopolitical relationships incorporate social, economic, political, and historical features of the states that interact with purely geographical elements to influence the strategic thinking and behavior of nations in the international sphere.

Coined in 1899 by the Swedish theorist Rudolf Kjellen, the term "geopolitics" combines the logic of the search for security and competition for dominance among states with geographical methodology. *Geopolitics* must not, however, be confused with *political geography*, which focuses on individual states' territorial sizes, boundaries, resources, internal political relations, and relations with other states.

Geopolitical is a term frequently used by military and political strategists, politicians and diplomats, political scientists, journalists, statesmen, and a variety of other government officials, such as policy planners and intelligence analysts.

Power Struggles Among States. The idea of geopolitics arises in the course of what might be considered the universal struggle for power among the world's most powerful nations, which compete for political and military leadership. How one state can threaten another, for example, is often influenced by geographical factors in combination with technological, social, economic and other factors. The extent to which individual states can threaten each other depends in no small measure on purely geographical considerations.

By the close of twentieth century the Cold War that had dominated world security concerns was over. Nevertheless, the United States still worried about the danger of being attacked by nuclear missiles fired, not by the former Soviet Union, but by irresponsible, fanatical, or suicidal states. American political leaders and military planners were concerned with the geographical position of so-called "rogue states." or "states of concern." In the year 2000 the two most prominently mentioned states that were potentially of this kind were Iran and North Korea. However, others could emerge.

Geographical factors play prominent roles in assessments of the different threats that those states presented to American interests. How far those states are located from American territory determines whether their missiles might pose a serious threat. A missile may be able to reach only the periphery of U.S. soil, or it might be able to carry only a small payload. Similar considerations determine the threat such states pose for U.S. forces stationed abroad, as well as for such important U.S. allies as Japan, Western Europe, or Israel. Such questions are thus said to constitute geopolitical, or geostrategic, considerations.

There are many examples of the influence of geopolitical factors on international relations among nations in the past. For example, the Bosporus, the narrow sea lane linking the Black Sea and the Mediterranean where Istanbul is situated, has long been considered of great strategic importance. In the nineteenth century, the Bosporus was the only direct route through which the Russian navy could reach southern Europe and the Mediterranean Sea.

Because of Russia's nineteenth century history of expansionism and its integration into the pre-World War I European state system, with its networks of competing military alliances, the Bosporus took on added geopolitical meaning. It was the congested (and therefore vulnerable) space through which Russian naval power had to pass to reach the Mediterranean.

Historical Origins of Geopolitics. Although political geography was a well-established field by the late nineteenth century, geopolitics was just beginning to emerge as a field of study and political analysis at the end of the century. In 1896 the German theorist Friedrich Ratzel published his *Political Geography,* which put forward the idea of the state as territory occupied by a people bound together by an idea of the state. Ratzel's theory embraced Social Darwinist notions that justified the current boundaries of nations. Ratzel viewed the state as a biological organism in competition for land with other states. The ethical implication of his theory seemed to be that "might makes right."

That theme set the stage for later German geopolitical thought, especially the notion of the need for *Lebensraum* (living room)—space into which the people of a nation could expand. German dictator Adolf Hitler justified his attack on Russia during World War II partly upon his claim that the German people needed more *Lebensraum* to the east. To some modern geographers, the use of geopolitical theories to serve German fascism and to justify other instances of military aggression tarnished geopolitics itself as a field of study.

Historical Development of Geopolitics. Modern geopolitics has further origins in the work of the Scottish geographer Sir Halford John Mackinder. In 1904 he published a seminal article, "The Geographical Pivot of History," in which he argued that the world is made up of a Eurasian "heartland" and a secondary hinterland (the remainder of the world), which he called the "marginal crescent." According to his theory, international politics is the struggle to gain control of the heartland. Any state that managed that feat would dominate the world.

A major proposition of Mackinder's theory was that geographical factors are not merely causative factors, but coercive. He tried to describe the physical features of the world that he believed directed human actions. In his view, "Man and not nature initiates, but nature in large measure controls." Geopolitical factors were therefore to a great extent determinants of the behavior of states. If this were true, geopolitics as a science could have deep relevance and corresponding influence among governments.

After Mackinder's time, the concept of geopolitics had a double significance. On the one hand it was a purely descriptive theory of geographic causation in history. On the other hand, its purveyors also believed, as Mackinder argued in 1904, that geopolitics has "a practical value as setting into perspective some of the competing forces in current international politics." Mackinder sought to promote this field of study as a companion to British statecraft, a tool to further Britain's national interest. By extension, geopolitical theory could assist any government in forming its political/military strategy.

As applied to the early twentieth-century world of international politics, however, Mackinder's theory had major weaknesses. Among his most glaring oversights were his failure to appreciate the rise of the United States, which attained considerable naval power after the turn of the century. Also, he failed to foresee the crucial strategic role that air power would play in warfare—and with it the immense change that air power could make in geopolitical considerations. Air power moves continents closer together, revolutionizing their geopolitical relationships.

One of Mackinder's chief critics was Nicolas John Spykman. Spykman argued that Mackinder had overvalued the potential economic, and therefore political, power of the Eurasian heartland, which could never reach its full potential because it could not overcome the obstacles to internal transportation. Moreover, the weaknesses of the remainder of the world—in effect, northern, western and southern Europe—could be overcome through forging alliances.

The dark side of geopolitical thought as handmaiden to political and military strategy became apparent in the Germany of the 1920's. At that time German theorists sought the resurrection of a German state broken by failure in World War I, the harsh terms of the Versailles Treaty that ended the war, and the hyperinflation that followed, wiping out the German middle class. In his 1925 article "Why Geopolitik?" Karl Haushofer urged the practical applications of *Geopolitik*. He urged that this form of analysis had not only "come to stay" but could also form important services for German political leaders, who should use all available tools "to carry on the fight for Germany's existence."

Haushofer ominously suggested that the "struggle" for German existence was becoming increasingly difficult because of the growth of the country's population. A people, he wrote, should study the living spaces of other nations so it could be prepared to "seize any possibility to recover lost ground." This discussion clearly implied that, from geopolitical necessity, Germany should seek additional territory to feed itself—a view carried into effect by Hitler in his quest for *Lebensraum* in attacking the Soviet Union, including its wheat-producing breadbasket, the Ukraine.

After World War II, a chastened Haushofer sought to soft-pedal both the direction and influence of his prewar writings. However, Hitler's morally heinous use of *Geopolitik* left geopolitical theorizing permanently tainted, in some eyes. Nevertheless, there is no necessary connection between geopolitics as a purely analytic description and geopolitics as the basis for a selfish search for power and advantage.

Geopolitics in the Twenty-first Century. Geopolitical considerations were unquestionably of profound relevance to the principal states of the post-World War II Cold War period. After the fall of the Berlin Wall in 1989, however, some theorists thought that the age of geopolitics had passed. In 1990 American strategic theorist Edward N. Luttwak, for example, argued that the importance of military power in international affairs had declined precipitously with the winding down of the Cold War. Military power had been overtaken in significance by economic prowess. Consequently, geopolitics had been eclipsed by what Luttwak called "geoeconomics," the waging of geopolitical struggle by economic means.

The view of Luttwak and various geographers of the declining significance of military power and geopolitical analysis, however, was soon proved to be overdrawn by events. As early as the first months of 1991, before the Soviet Union was officially dismantled, military power asserted itself as a key determinant on the international scene. Led by the United States, a far-flung alliance of nations participated in a war to remove Iraqi dictator Saddam Hussein's forces from neighboring Kuwait, which Iraq had illegally occupied. The decisive and successful use of military power in that war dramatically disproved assertions of its growing irrelevance.

Similarly, at the outset of the twenty-first century, military power retained its preeminence in the dynamics of international politics, even as economic forces were seen to gather momentum. To states throughout Asia and the West (especially Western Europe and the United States), the relative military capability of potential adversaries, and therefore geopolitics, remained a vital feature of the international order. Central to this view of the world scene is the growing military rivalry of the United States and China in East Asia. As China modernizes and expands its nuclear and conventional forces, it may feel itself capable of challenging America's predominant military power and prestige in East Asia. This possibility heightens the use of geopolitical thinking, giving it currency in analyzing this emerging situation.

Geopolitics as Civilizational Clash. A recent and sometimes controversial expression of geopolitical analysis has been offered by Samuel Huntington of Harvard University. In his *The Clash of Civilizations and the Remaking of World Order* (1996) Huntington constructs a theory to explain certain tendencies of international behavior. He divides the world into a number of cultural groupings, or "civilizations," and argues that the character of various international conflicts can best be explained as conflicts or clashes of civilizations. In his view, Western civilization differs from the civilization of Orthodox Christianity, with a variety of conflicts erupting between the two. An example is the attack by the North Atlantic Treaty Organization (NATO), the bastion of the West, on Serbia, which is part of the Orthodox East.

Huntington's other civilizations include Islamic, Jewish, Eastern Caribbean, Hindu, Sinic (Chinese), and Japanese. The clash between Israel and its neighbors, the struggle between Pakistan and India over Kashmir, the rivalries between the United States and China and between China and India, for example, can be viewed as civilizational conflicts. Huntington has stated, however, that his theory is not intended to explain all of the historical past, and he does not expect it to remain valid long into the future. Instead, he believes it may remain a relevant tool of analysis only until around 2015, after which it will have become dated.

Charles F. Bahmueller

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International Boundaries

International boundaries are the marked or imaginary lines traversing natural terrain of land or water that mark off the territory of one politically organized society—a state or nation-state—from other states. In addition, states claim "air boundaries." While satellites circumnavigate the earth without nations' permission, airplanes and other air vessels that fly much lower must gain the permission of states over whose territory they travel.

The existence of international boundaries is a consequence of the "territoriality" that is a feature of modern human societies. All politically organized societies, except for nomadic tribes, claim to rule some exactly defined geographical territory. International boundaries provide the limits that define this territory.

The subject of international boundaries is so complex that an encyclopedia on the subject exists and an academic unit of Durham University in Great Britain is devoted to the subject. Many highly trained individuals devote their professional lives to the subject in universities, government agencies, and other settings.

International boundaries have ancient origins. For example, the oldest sections of the Great Wall of China date back to the Ch'in Dynasty of the second century B.C.E. The Roman Empire also maintained boundaries to its territories, such as Hadrian's Wall in the north of England, built by the Romans in 122 C.E. as a defensive barrier against marauders. In these and other ancient instances, however, there was little thought that borders must be exact.

The existence of precisely drawn boundaries among states is relatively recent. The modern state has existed for no more than a few hundred years. In addition, means to determine many boundaries have come into existence only in the nineteenth and twentieth centuries, with the invention of scientific methods and instruments, along with accompanying vocabulary, for determining exact boundaries. The most basic terms of this vocabulary begin with "latitude" and "longitude" and their subdivisions into the "minutes" and "seconds" used in determining boundaries. In modern times, a new attitude toward states' territory was born, especially with the nineteenth century forms of nationalism, which tend to regard every acre of territory as sacred.

Types of Boundaries. There are several types of international boundaries. Some are geographical features, including rivers, lakes, oceans, and seas. Thus boundaries of the United States include the Great Lakes, which border Canada to the north; the Rio Grande, a river that forms part of the U.S. boundary with Mexico to the south; the Atlantic and Pacific Oceans, to the east and west, respectively; and the Gulf of Mexico, to the south. In Africa, Lake Victoria bounds parts of Tanzania, Uganda, and Kenya; and rivers, such as sections of the Congo and the Zambezi, form natural boundaries among many of the continent's states.

Other geographical features, such as mountains, often form international boundaries. The Pyrenes, for example, separate France and Spain and cradle the tiny state of Andorra. In South America, the Andes frequently serve as a boundary, such as between Argentina and Chile. The Himalayas in South Central Asia create a number of borders, such as between India, China, and Tibet and between Nepal, Butan, and their neighbors. When there are no clear geographical barriers between states, boundaries must be decided by mutual consent or the threat of force.

Creation and Change of International Boundaries. War and conquest often have been used to determine borders. Such wars, however, historically have created hostility among losers. Political pressures to recover lost lands build up among aggrieved losers, and such irredentist claims provide fuel for future wars. A classic example is the fate of the regions of Alsace and Lorraine between France and Germany. Although natural resources in the form of coal played a substantial role in the dispute over this area, national pride was also a potent element.

Whether boundaries are fixed through compelling geographical imperatives or in their absence, states typically sign treaties agreeing to their location. These may be treaties that conclude wars, or boundary commissions set up by those involved may draw up borders to which states give formal agreement. In 1846, for example, negotiators for Great Britain and the United States settled on the forty-ninth parallel as the boundary between the western United States and Canada, although in the United States, "Fifty-four [degrees latitude] Forty [minutes] or Fight" had been a popular motto in the presidential election campaign of 1844.

Sometimes no accepted borders exist because of chronic hostility between states. Thus, maps of the Kashmir region between India and Pakistan, claimed by both countries, show only a "line of control" or cease-fire line to divide the two warring states. Similarly, only a cease-fire line, drawn at the armistice of the Korean War of 1950-1953, divides North and South Korea; a mutually agreed-upon border remains unfixed.

In rare instances, no true boundary exists to mark where a state's territory begins and ends. Classic cases are found on the Arabian Peninsula, where the land borders of principalities, known as the Gulf Sheikdoms, are vague lines in the sand. Such circumstances usually create no difficulties where nothing is at stake, but when oil is discovered, states must come to agreement or risk coming to blows.

In other instances, negotiations and international arbitration have been effective for determining borders. Perhaps the most important principle for determining the borders of newly created states is found in the Latin phrase, *Uti possidetis iurus.* This principle is used when states become independent after having been colonies or constituent parts of a larger state that has broken up. The principle holds that states shall respect the borders in place when they were colonies. *Uti possidetis* was first extensively used in South America in the nineteenth century, when European colonial powers withdrew, leaving several newly born states to determine their own boundaries. It was also used when African colonies became independent in the late twentieth century.

Besides war and negotiation, purchase has sometimes been a means of creating international boundaries. For example, in 1853 the United States purchased territory from Mexico in the southwest; in 1867, it purchased Alaska from Russia.

In rare cases, natural boundaries may change naturally or be changed deliberately by one side, incurring resentment among victims. An example occurred in 1997, when Vietnam complained that China had built an embankment on a border river that caused the river to change its course; China countered that Vietnam had built a dam altering the river's course.

Other border difficulties among states include conflicts over water that flows from one country to another. In the 1990's, for example, Mexico complained of excessive U.S. use of Colorado River waters and demanded adjustment.

Border Disputes. Border disputes among states in the past two centuries have been numerous and lethal. In the twentieth century, numerous such controversies degenerated into violence. In Asia, India and Pakistan fought over Kashmir, beginning in 1947-1949 and recurring in 1965 and 1999. China has been involved in violent border disputes with India, especially in 1962; Vietnam in 1979; and Russia in 1969. In South America, border wars between Ecuador and Peru broke out in 1941, 1981, and 1995. This dispute was settled by negotiation in 1998. In Africa, among numerous recent armed conflicts, the bloody border conflict between Eritrea and Ethiopia in the 1990's was notable.

Other recent disputes have ended peacefully. Eritrea avoided violence with Yemen over several Red Sea islands by accepting arbitration by an international tribunal. In 1995 Saudi Arabia and the United Arab Emirates negotiated a peaceful agreement to their border dispute involving oil rights.

Many unresolved boundary disputes might yet lead to conflicts. Among the most complex is the multinational dispute over the six hundred tiny Spratly Islands in the South China Sea. Uninhabited but potentially valuable because of oil, the Spratlys are claimed by China, Brunei, Malaysia, Indonesia, the Philippines, Taiwan, and Vietnam.

Border Policies. Problems with international borders are not limited to territorial disputes. Policies regarding how borders should be oper-

A Peacefully Resolved Border Dispute

The peaceful resolution of the border dispute between the Southern African states of Botswana and Namibia was hailed by observers of African politics. Instead of resorting to the armed warfare that so often has marked similar disputes on the continent, the two states chose a different course in 1996, when they found negotiations stalemated. They submitted their claims to the International Court of Justice in The Hague and agreed to accept the court's ruling. Late in 1999, by an eleven-to-four vote, the court ruled for Botswana, and Namibia kept its word to embrace the decision. At issue was a tiny island in the Chobe River on Botswana's northern border. An 1890 treaty between colonial rulers Great Britain and Germany had described the border at the disputed point vaguely, as the river's "main channel." The court took the course of the deepest channel to mark the agreed boundary, giving Botswana title to the 1.4-square-mile (3.5-sq.-km.) territory.

ated—including the key questions of who and what should be allowed entrance and exit under what conditions—can be expected to continue as long as independent states exist. While the members of the European Union have agreed to allow free passage of people and goods among themselves, this policy does not extent to nonmembers.

The most important purpose of states is to protect the lives and property of their citizens. One of the principal purposes of international boundaries is to further this purpose. Most states insist on controlling their borders, although borders seem increasingly porous. Given the imperatives of control and the increasing difficulties of maintaining it, issues surrounding international borders are expected to continue indefinitely in the twenty-first century.

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Geography Basics

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MAGILL'S CHOICE

Geography Basics

Volume 2

Glossary
Appendices

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GLOSSARY

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This glossary defines terms and concepts mentioned in the main text. Words printed in SMALL CAPITAL LETTERS *have entries of their own here.*

Aa. Hawaiian term (pronounced "ah-ah") that has been adopted for LAVA flows with rough, clinkery surfaces.

Geologist examining a large solidified flow of aa lava from Mauna Ulu on the island of Hawaii. (U.S. Geological Survey)

Ablation. Loss of ice volume or mass by a GLACIER. Ablation includes melting of ice, SUBLIMATION, DEFLATION (removal by WIND), EVAPORATION, and CALVING. Ablation occurs in the lower portions of glaciers.

Ablation, zone of. In a GLACIER, at the SNOUT of the glacier where ice is lost through melting and SUBLIMATION.

Abrasion. Wearing away of ROCKS in STREAMS by grinding, especially when rocks and SEDIMENT are carried along by stream water. The STREAMBED and VALLEY are carved out and eroded, and the rocks become rounded and smoothed by abrasion.

Absolute age. Numerical timing (in years or millions of years) of a geologic event, as contrasted with relative (stratigraphic) timing; a date that gives an actual age, though it may be approximate, of an artifact.

Absolute humidity. Mass of water vapor contained in a unit volume of moist AIR. Absolute humidity is usually measured as grams of water vapor per cubic meter of air. More important to geographers is the RELATIVE HUMIDITY.

Absolute location. Position of any PLACE on the earth's surface. The absolute location can be given precisely in terms of DEGREES, MINUTES, and SECONDS of LATITUDE (0 to 90 degrees north or south) and of LONGITUDE (0 to 180 degrees east or west). The EQUATOR is 0 degrees latitude; the PRIME MERIDIAN, which runs through Greenwich in England, is 0 degrees longitude.

Abyss. Deepest part of the OCEAN. Modern TECHNOLOGY—especially sonar—has enabled accurate mapping of the ocean floors, showing that there are MOUNTAIN CHAINS, OT RIDGES, in all the oceans, as well as deep CANYONS OT TRENCHES closer to the edges of the oceans.

Abyssal. Referring to the deep-OCEAN floor. The part of the CONTINENT under shallow water is the CONTINENTAL SHELF. At the outer edge of the continental shelf is a steep fall or CLIFF, called the CONTINENTAL SLOPE. Beyond this is the ABYSSAL PLAIN.

Abyssal plain. Broad flat areas beneath the OCEAN at the base of the continental rise, at depths ranging from 1,200 to 3,500 feet (2,000-6,000 meters). Individual MOUNTAIN peaks can occur on abyssal plains. Close to 40 percent of the oceans are abyssal plain.

Abyssal seafloor. Abyssal plains of the OCEANS lie beyond the CONTINENTAL MARGINS at depths greater than 6,000 feet (2,000 meters). They are thought to be the flattest areas on the earth and are carpeted with thick layers of SEDIMENT. Their greatest economic value lies in the metallic MINERALS that form part of these sediments.

Acclimatization. Gradual adjustment of living organisms, especially humans, to climatic conditions other than those to which they are accustomed.

Acculturation. Modification of a CULTURE when its people come into contact with another culture. Generally, acculturation occurs when INDIGENOUS PEOPLES come into contact with a technically superior culture, as during the period of colonial empires. The globalization of entertainment (movies and television) has acculturated many societies to American culture. Compare with TRANSCULTURATION.

Accumulation, zone of. In a GLACIER, the part where ice accumulates as new SNOW falls each year.

Acid deposition. *See* ACID RAIN.

Acid rain. PRECIPITATION containing high levels of nitric or sulfuric acid; a major environmental problem in parts of North America, Europe, and Asia. Natural precipitation is slightly acidic (about 5.6 on the pH SCALE), because CARBON DIOXIDE—which occurs naturally in the ATMOSPHERE—is dissolved to form a weak carbonic acid. In areas where heavy industry is located, oxides of sulphur and/or nitrogen combine with atmospheric moisture to produce sulfuric acid or nitric acid, respectively. In the worst-affected parts of North America and Europe, pH as low as 2.0 has been recorded, which is more acidic than lemon juice or vinegar. As a result, thousands of LAKES and STREAMS in North

America and Europe can no longer support fish; FORESTS in Switzerland, Germany, and Poland have been damaged extensively. Buildings also are eroded by acid deposition, so that cathedrals and monuments are being destroyed. Often called acid rain; however, SNOW, SLEET, and hail can also be acid.

Acoustic echo sounding. Also known as sonar, method of determining the depth of the OCEAN floor that measures the time of a reflected sound wave and relates that to distance.

Adiabatic. Change of TEMPERATURE within the ATMOSPHERE that is caused by compression or expansion without addition or loss of heat.

Advection. Horizontal movement of AIR from one PLACE to another in the ATMOSPHERE, associated with WINDS. See also CONVECTION.

Advection fog. FOG that forms when a moist AIR mass moves over a colder surface. Commonly, warm moist air moves over a cool OCEAN CURRENT, so the air cools to SATURATION POINT and fog forms. This phenomenon, known as sea fog, occurs along subtropical west COASTS. Advection fogs are common in San Francisco, especially in summer.

Aeolian. See EOLIAN.

Aerate. To supply with or expose to a gas.

Aeration, zone of. Area directly below the ground surface that contains some water as SOIL MOISTURE, but much of the pore space is filled with AIR in the spaces between the soil particles. At the bottom of the zone of aeration is the WATER TABLE.

Aerosol. Substances held in SUSPENSION in the ATMOSPHERE, as solid particles or liquid droplets.

Aftershock. EARTHQUAKE that follows a larger earthquake and originates at or near the focus of the latter; many aftershocks may follow a major earthquake, decreasing in frequency and magnitude with time.

Agglomerate. Type of ROCK composed of volcanic fragments, usually of different sizes and rough or angular.

Agglomeration effect. Certain industries can obtain cost advantages by locating production among functionally related industries or activities. This occurs chiefly because transport costs are reduced. During the INDUSTRIAL REVOLUTION, manufacturing became concentrated near coalfields for this reason.

Aggradation. Accumulation of SEDIMENT in a STREAMBED. Aggradation often results from reduced flow in the channel during dry periods. It also occurs when the STREAM's load (BEDLOAD and SUSPENDED LOAD) is greater than the stream capacity. A BRAIDED STREAM pattern often results.

Agribusiness. Modern type of commercial agricultural production in which a company owns large areas of farmland and is concerned with not only the production of agricultural commodities, but also their transport, storage, processing, and distribution. The word is a combination of "agriculture" and "business." In the United States, agribusiness accounts for about one-fifth of the GROSS DOMESTIC PRODUCT.

Agricultural Revolution. Also known as the Agrarian Revolution, historical change from a nomadic lifestyle of HUNTING AND GATHERING or nomadic herding to a sedentary one based on the growing of crops. Scholars believe that this change first occurred in the area of the Middle East known as Mesopotamia at least eleven thousand years ago. Grain, varieties of either wheat or barley, was harvested for human consumption and for feeding domesticated animals, such as cattle or sheep. On other CONTINENTS, agriculture was practiced with different crops: squash and corn in the Valley of Mexico, LEGUMES in Southeast Asia. These changes made possible the growth of cities and CIVILIZATIONS. Over the centuries, agricultural production has been increased by IRRIGATION, new varieties of crops and animals, use of agricultural implements and machinery, CROP ROTATION, selective breeding, and genetic engineering.

Agriculture. Growing of crops and raising of LIVESTOCK. Agriculture provides food for human consumption and such products as wool, cotton, and lumber. See also AQUACULTURE.

Air. Colorless, odorless, tasteless, formless mixture of gases that make up the earth's ATMOSPHERE. Comprises almost 78 percent nitrogen and almost 21 percent oxygen, together with small amounts of water vapor, argon, CARBON DIOXIDE, neon, helium, methane, krypton, hydrogen, and other gases, together with minute particles. Air is a synonym for atmosphere; some writers describe the earth's atmosphere as an ocean of air.

Air current. Air currents are caused by differential heating of the earth's surface, which causes heated air to rise. This causes WINDS at the surface as well as higher in the earth's ATMOSPHERE.

Air drainage. Flow of cold, dense air down slopes in response to GRAVITY.

Air mass. Large body of air with distinctive homogeneous characteristics of TEMPERATURE, HUMIDITY, and stability. It forms when air remains stationary over a source REGION for a period of time, taking on the conditions of that region. An air mass can extend over a million square miles with a depth of more than a mile. Air masses are classified according to moisture content (*m* for maritime or *c* for continental) and temperature (*A* for ARCTIC, *P* for polar, *T* for tropical, or *E* for equatorial). The air masses affecting North America are mP, cP, and mT. The interaction of AIR masses produces WEATHER. The line along which air masses meet is a FRONT.

Air pollution. Airborne pollution generated from both natural and manmade sources. Natural sources include pollen from plants, gases and PARTICULATE MATTER from VOLCANOES, and windblown DUST. Artificial sources include industrial and automobile emissions and airborne particles associated with human-induced ABRASION.

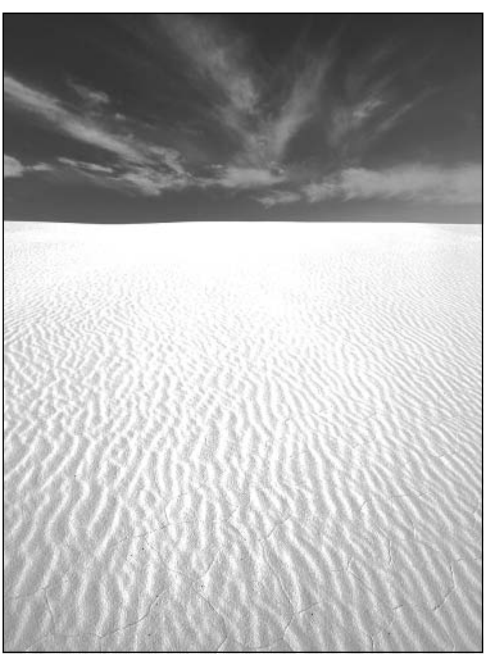
Air pressure. See ATMOSPHERIC PRESSURE.

Albedo. Measure of the reflective properties of a surface; the ratio of reflected ENERGY (INSOLATION) to the total incoming energy, expressed as a percentage. The albedo of Earth is 33 percent.

Alberta Clipper. Cold STORM that forms as a low to the east of the Rockies, over Alberta, Canada, and moves rapidly southeast. It brings cold TEMPERATURES, PRECIPITATION, and occasionally heavy SNOW to the northeast United States.

Alienation (land). Land alienation is the appropriation of land from its original owners by a more powerful force. In preindustrial societies, the ownership of agricultural land is of prime importance to subsistence farmers. Colonial governments claimed ownership of the REGIONS they colonized, even though native peoples had lived there for thousands of years. Land in Mexico was alienated by Spain; in Indonesia by the Dutch; and in Australia by the British. The government of the United States alienated most of the lands formerly occupied by NATIVE AMERICANS, leaving them only small "reserves." Some countries have passed laws that attempt to prevent land alienation by foreigners. In Fiji, for example, only Fijians can own or purchase land; the large Indian POPULATION can only lease farmland from Fijian owners.

Alkali flat. Dry LAKEBED in an arid REGION, covered with a layer of SALTS. A well-known example is the Alkali Flat area of White Sands National Monument in New Mexico; it is the bed of a large lake that formed when the GLACIERS were melting. It is covered with a form of gypsum crystals called selenite. This material is blown off the surface into large SAND DUNES. Also called a salina. See also BITTER LAKE.



New Mexico's White Sands National Monument is a well-known example of an alkali flat. (PhotoDisc)

Allogenic sediment. SEDIMENT that originates outside the PLACE where it is finally deposited; SAND, SILT, and CLAY carried by a STREAM into a LAKE are examples.

Alluvial fan. Common LANDFORM at the mouth of a CANYON in arid REGIONS. Water flowing in a narrow canyon immediately slows as it leaves the canyon for the wider VALLEY floor, depositing the SEDIMENTS it was transporting. These spread out into a fan shape, usually with a BRAIDED STREAM pattern on its surface. When several alluvial fans grow side by side, they can merge into one continuous sloping surface between the HILLS and the valley. This is known by the Spanish word *bajada*, which means "slope."

Alluvial plain. See FLOODPLAIN.

Alluvial system. Any of various depositional systems, excluding DELTAS, that form from the activity of RIVERS and STREAMS. Much alluvial SEDIMENT is deposited when rivers top their BANKS and FLOOD the surrounding countryside. Buried alluvial sediments may be important water-bearing RESERVOIRS or may contain PETROLEUM.

Alluvium. Material deposited by running water. This includes not only fertile SOILS, but also CLAY, SILT, or SAND deposits resulting from FLUVIAL processes. FLOODPLAINS are covered in a thick layer of alluvium.

Alpine. Related to high MOUNTAINS. The alpine OROGENY refers to an episode of mountain formation between 20 and 120 million years ago, which produced the European Alps.

Alpine glacier. Mass of ice and SNOW that moves slowly down from the PEAKS to produce the spectacular LANDFORMS associated with high

Alpine glaciers are characterized by their formation on spectacularly steep mountain slopes. (PhotoDisc)

MOUNTAIN scenery. Active glaciers may threaten lives and property through catastrophic forward surges and floodwater, or they may be essential sources of MELTWATER in dry areas.

Alternative energy. Renewable forms of ENERGY such as SOLAR, HYDROelectric, wind, and tidal power; sometimes called sustainable energy. Compare with NONRENEWABLE energy from COAL, OIL, NATURAL GAS.

Altimeter. Instrument for measuring ALTITUDE, or height above the earth's surface, commonly used in airplanes. An altimeter is a type of ANEROID BAROMETER.

Altiplanos. South American term for high PLAINS.

Altitude. Height above the earth's surface, measured from MEAN SEA LEVEL. Pressure decreases regularly with increased altitude, but TEMPERATURE rises or falls depending on the layer of the ATMOSPHERE at which it is measured. The fall of temperature throughout the TROPOSPHERE (the lowest layer of the atmosphere) leads to ALTITUDINAL ZONATION.

Altitudinal zonation. Existence of different ECOSYSTEMS at various ELEVATIONS above SEA LEVEL, due to TEMPERATURE and moisture differences. This is especially pronounced in Central America and South America. The hot and humid COASTAL PLAINS, where bananas and sugarcane thrive, is the *tierra caliente.* From about 2,500 to 6,000 feet (750 to 1,800 meters) is the *tierra templada*; crops grown here include coffee, wheat, and corn, and major cities are situated in this zone. From about 6,000 to 12,000 feet (1,800 to 3,600 meters) is the *tierra fria*; here only hardy crops such as potatoes and barley are grown, and large numbers of animals are kept. From about 12,000 to 15,000 feet (3,600 to 4,500 meters) lies the *tierra helada,* where hardy animals such as sheep and alpaca graze. Above 15,000 feet (4,500 meters) is the frozen *tierra nevada*; no permanent life is possible in the permanent SNOW and ICE FIELDS there.

Altocumulus. Puffy CLOUD masses at a middle ALTITUDE, between 20,000 and 43,000 feet (6,000 to 13,000 meters) above the earth's surface. Sizes and shapes of these clouds vary; their colors are grey and white.

Altostratus. Layers of CLOUD covering a large part of the sky at a middle ALTITUDE, between 20,000 and 43,000 feet (2,000 to 6,000 meters) above the earth's surface. Altostratus clouds may produce continuous rain. Usually a uniform grey or blue grey in color. The SUN may shine weakly through altostratus clouds.

Amerindians. Contraction of "American Indians"; widely accepted term for the native peoples of the Caribbean, Central America, and North America. See also NATIVE AMERICANS.

Anabatic wind. Upslope WIND, blowing up a HILL OR MOUNTAIN as the result of strong surface heating of the slopes. Similar to a valley BREEZE.

Andesite. Volcanic IGNEOUS ROCK type intermediate in composition and density between GRANITE and BASALT.

Anemometer. Instrument for measuring WIND speed or wind velocity, consisting of a set of cups or cones that rotate as the wind blows into them. See also ALTIMETER; BAROMETER.

Aneroid barometer. Sealed, partially evacuated box connected to a needle and dial, used to measure changes in ATMOSPHERIC PRESSURE. See also ANEMOMETER; BAROMETER.

Angle of repose. Maximum angle of steepness that a pile of loose materials such as SAND OR ROCK can assume and remain stable; the angle varies with the size, shape, moisture, and angularity of the material.

Animism. Belief that natural features, such as LANDFORMS, plants, and animals, possess a spirit. This spirit can intervene in the real world to bring good or bad fortune to a person. In religious terms, gods dwell in certain sacred PLACES, or take the shape of a certain animal. Alternatively, a person's soul or spirit may pass into a certain animal or landform after death. An animistic view of nature is still found in many African CULTURES. The Australian Aborigines have an animist view of the land and its inhabitants. Although animism is sometimes characterized as primitive, it is thought that all RELIGIONS began as animist beliefs and customs. Animism is regarded favorably by conservationists as an environmentally responsible philosophy.

Anorthosite. IGNEOUS ROCK, solidified from the molten state, consisting mostly of FELDSPAR. Coarse-grained, INTRUSIVE igneous rocks composed principally of plagioclase feldspar, anorthosites are useful for what they reveal about the early crustal evolution of the earth, and they are the source of several economic commodities.

Antarctic. Relating to the REGION south of the Antarctic Circle, extending from 66.5 DEGREES south to the South Pole at 90 degrees south. The CONTINENT of Antarctica is located there. The international Antarctic Treaty allows for scientific research in Antarctica by several NATIONS, but prohibits military use.

Antecedent river. STREAM that was flowing before the land was uplifted and was able to erode at the pace of UPLIFT, thus creating a deep CANYON. Most deep canyons are attributed to antecedent rivers. In the Davisian CYCLE OF EROSION, this process was called REJUVENATION.

Anthropocentric. Regarding humanity as the center or most important consideration. An anthropocentric view of nature holds that all plants and animals exist primarily for human use and benefit.

Anthropogeography. Branch of GEOGRAPHY founded in the late nineteenth century by German geographer Friedrich Ratzel. The field is closely related to human ECOLOGY—the study of humans, their DISTRIBUTION over the earth, and their interaction with their physical ENVIRONMENT.

Anticline. Area where land has been UPFOLDED symmetrically. Its center contains stratigraphically older ROCKS. See also SYNCLINE.

Anticyclone. High-pressure system of rotating WINDS, descending and di-

Anticline on the banks of the Potomac River. (U.S. Geological Survey)

verging, shown on a WEATHER chart by a series of closed ISOBARS, with a high in the center. In the NORTHERN HEMISPHERE, the rotation is CLOCKWISE; in the SOUTHERN HEMISPHERE, the rotation is COUNTER-CLOCKWISE. An anticyclone brings warm weather. See also CYCLONE.

Antidune. Undulatory upstream-moving bed form produced in free-surface flow of water over a SAND bed in a certain RANGE of high flow speeds and shallow flow depths.

Antipodes. TEMPERATE ZONE of the SOUTHERN HEMISPHERE. The term is now usually applied to the countries of Australia and New Zealand. The ancient Greeks believed that if humans existed there, they must walk upside down. This idea was supported by the Christian Church in the Middle Ages.

Antitrade winds. WINDS in the upper ATMOSPHERE, or GEOSTROPHIC winds, that blow in the opposite direction to the TRADE WINDS. Antitrade winds blow toward the northeast in the NORTHERN HEMISPHERE and toward the southeast in the SOUTHERN HEMISPHERE.

Aperiodic. Irregularly occurring interval, such as found in most WEATHER CYCLES, rendering them virtually unpredictable.

Aphelion. Point in the earth's 365-DAY REVOLUTION when it is at its greatest distance from the SUN. This is caused by Earth's elliptical

ORBIT around the Sun. The distance at aphelion is 94,555,000 miles (152,171,500 km.) and usually falls on July 4. The opposite of PERIHELION.

Aplite. Light-colored, sugary-textured granitic ROCK generally found as small, late-stage VEINS in GRANITES of normal TEXTURE; in pegmatites, aplites usually form thin marginal selvages against the country rock but may also occur as major lenses in the pegmatite interior.

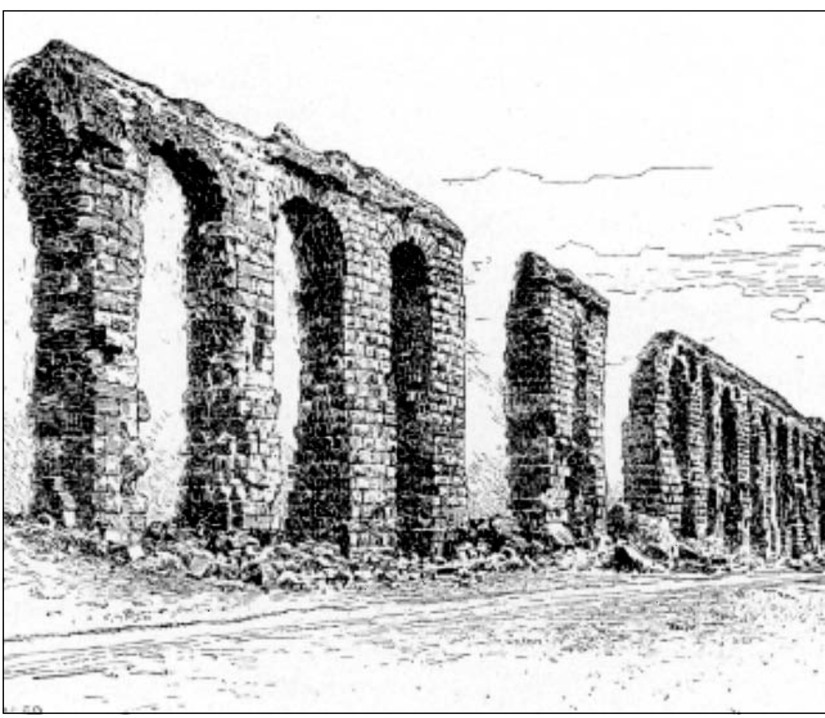
Apogee. Point in the MOON's ORBIT when it is most distant from the center of the earth.

Aposelene. Earth's farthest point from the MOON.

Apparent solar time. Time shown on a sundial; also known as apparent time. Because the elliptical path of the earth around the SUN causes the apparent solar DAY to vary, there can be a difference of almost four minutes in the length of a day. When accurate CLOCKS and watches were developed in the seventeenth century, mean solar time was adopted instead of apparent solar time.

Aquaculture. Commercial raising and harvesting of food such as fish, shellfish, or seaweed in artificial ponds or in selected portions of RIVERS or coastal waters.

Aqueduct. Artificial conduit for carrying water. See also CANAL.



Ruins of Roman aqueduct at Carthage in what is now Tunis. (Arkent Archive)

Aquifer. Underground body of porous rock that contains water and allows water percolation through it. The largest aquifer in the United States is the Ogallala Aquifer, which extends south from South Dakota to Texas.

Arable land. Land that is suitable for farming. A measure of the productivity of arable land is the physiologic density.

Archaeology. Science that investigates the human past through its material remains, such as pots, tools, buildings, and human remains.

Archipelago. Group of islands located close together; an island chain. Indonesia, comprising thirteen thousand islands, is the world's largest archipelago.

Arctic. Relating to the region north of the Arctic Circle, extending from 66.5 degrees north to the North Pole at 90 degrees north. Comes from the Greek word meaning bear, because the Arctic region is located under the constellation Ursa Major or Big Bear.

Arête. Serrated or saw-toothed ridge, produced in glaciated mountain areas by cirques eroding on either side of a ridge or mountain range. From the French word for knife-edge.

Arête and talus slopes in Colorado's San Juan Mountains. (U.S. Geological Survey)

Aridity. Lack of precipitation. No trees or woody plants can grow in arid regions, and vegetation is small and sparse.

Arroyo. Spanish word for a dry streambed in an arid area. Called a wadi in Arabic and a wash in English.

Artesian well. WELL from which GROUNDWATER flows without mechanical pumping, because the water comes from a CONFINED AQUIFER, and is therefore under pressure. The Great Artesian Basin of Australia has hundreds of artesian wells, called BORES, that provide drinking water for sheep and cattle. The name comes from the Artois REGION of France, where the phenomenon is common. A subartesian well is sunk into an UNCONFINED AQUIFER and requires a pump to raise water to the surface.

Aseismic. Lacking EARTHQUAKE activity.

Ash. Fine-grained pyroclastic material less than 2 millimeters in diameter, ejected from an erupting VOLCANO. See also VOLCANIC ASH.

Volcano spewing ash into the atmosphere. (PhotoDisc)

Ash flow. Density current composed of a highly heated mixture of volcanic gases and ASH, which travels down the flanks of a VOLCANO or along the ground surface.

Assimilation. Absorption of one cultural group into a larger or dominant cultural group through the former group's adoption of cultural traits such as LANGUAGE, clothing, and customs from the latter group. Immigrants to the United States in the nineteenth century were assimilated as part of the "melting pot"; in the late twentieth century, in contrast, retaining the original CULTURE was encouraged, as part of MULTICULTURALISM.

Asteroid. Small PLANET or celestial body made of ROCK that moves around the SUN, usually in an ORBIT between Mars and Jupiter, where there are approximately forty-five thousand asteroids.

Asteroid belt. REGION between the ORBITS of Mars and Jupiter containing the majority of ASTEROIDS.

Asthenosphere. Part of the earth's UPPER MANTLE, beneath the LITHOSPHERE, in which PLATE movement takes place. Also known as the low-velocity zone.

Astrobleme. Remnant of a large IMPACT CRATER on Earth.

Astrolabe. Medieval instrument used to measure the ALTITUDE of celestial bodies, especially the SUN.

Astronomical unit (AU). Unit of measure used by astronomers that is equivalent to the average distance from the SUN to Earth (93 million miles/150 million km.).

Atlas. Book of MAPS, often accompanied by CHARTS, tables, and illustrations. Named after the figure in Greek mythology who was condemned by Zeus to carry the heavens on his shoulders.

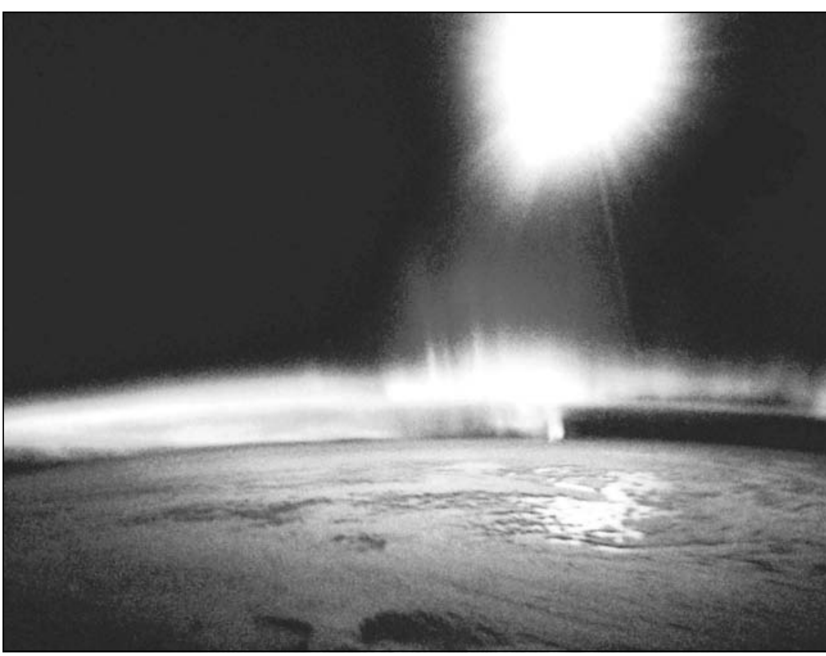
Atmosphere. Mixture of gases surrounding the earth. The atmosphere is thinner at the POLES than at the EQUATOR and varies with the SEASON, but averages 300 miles (480 km.) above the earth's surface. Beyond the atmosphere is the EXOSPHERE. The modern atmosphere differs from that of four billion years ago in that it contains oxygen. The modern atmosphere is 78 percent nitrogen by volume and almost 21 percent oxygen. Other atmospheric gases include argon, CARBON DIOXIDE, neon, helium, methane, and krypton. Small amounts of OZONE, nitrous oxide, hydrogen, and xenon also occur, as do variable amounts of water vapor and PARTICULATE MATTER. Some scientists believe that human activities are changing the atmosphere so rapidly that one can speak of an ANTHROPOGENIC atmosphere. GLOBAL WARMING is thought by many to be a result of anthropogenic change, especially the increase in carbon dioxide.

Atmospheric pressure. Weight of the earth's ATMOSPHERE, equally distributed over earth's surface and pressing down as a result of GRAVITY. On average, the atmosphere has a force of 14.7 pounds per square inch (1 kilogram per centimeter) squared at SEA LEVEL, also expressed as 1013.2 millibars. Variations in atmospheric pressure, high or low, cause WINDS and WEATHER changes that affect CLIMATE. Pressure decreases rapidly with ALTITUDE or distance from the surface: Half of the total atmosphere is found below 18,000 feet (5,500 meters); more than 99 percent of the atmosphere is within 30 miles (50 km.) of the surface. Atmospheric pressure is measured with a BAROMETER.

Atoll. Ring-shaped growth of CORAL REEF, with a LAGOON in the middle. Charles Darwin, who observed many Pacific atolls during his voyage on the *Beagle* in the nineteenth century, suggested that they were created from FRINGING REEFS around volcanic ISLANDS. As such islands sank beneath the water (or as SEA LEVELS rose), the coral continued growing upward. SAND resting atop an atoll enables plants to grow, and small human societies have arisen on some atolls. The world's largest atoll, Kwajalein in the Marshall Islands, measures about 40 by 18 miles (65 by 30 km.), but perhaps the most famous atoll is Bikini Atoll—the SITE of nuclear-bomb testing during the 1950's.

Atomic clock. Extremely precise timekeeper that uses the vibration or natural frequency of cesium atoms to measure time. The first atomic clock was built in the United States in 1949; the first using cesium in 1952. High-accuracy timekeeping became increasingly important with the advent of telecommunications, especially for the GLOBAL POSITIONING SYSTEM. World time, also called UTC or COORDINATED UNIVERSAL TIME, is now measured using standard clocks, which are all atomic clocks. The world's most accurate clock, the Cesium Fountain Clock NST F-1, went into operation at Boulder, Colorado, in late 1999. Its accuracy is such that it should not gain or lose a second if it were keep running for twenty million years.

Aurora. Glowing and shimmering displays of colored lights in the upper ATMOSPHERE, caused by interaction of the SOLAR WIND and the charged particles of the IONOSPHERE. Auroras occur at high LATITUDES. Near the North Pole they are called aurora borealis or northern lights; near the South Pole, aurora australis or southern lights.



Aurora borealis and bright moon, viewed from earth orbit. (Corbis)

Austral. Referring to an object or occurrence that is located in the SOUTHERN HEMISPHERE or related to Australia. Compare with BOREAL.

Australopithecines. Erect-walking early human ancestors with a cranial capacity and body size within the RANGE of modern apes rather than of humans.

Autumnal equinox. See EQUINOX.

Avalanche. Mass of SNOW and ice falling suddenly down a MOUNTAIN slope, often taking with it earth, ROCKS, and trees.

Axis of the earth. Imaginary line passing through the center of the earth from the North Pole to the South Pole. The earth rotates on its axis once in every twenty-four hours, in a COUNTERCLOCKWISE direction if viewed from above the North Pole, or in a west-to-east direction if viewed from above the EQUATOR. As a result, the SUN appears to rise in the east and set in the west.

Azimuth. DEGREES of arc measured CLOCKWISE from the north.

Azimuthal projection. Projection that can be visualized by imagining a sheet of paper resting at a point on the surface of a center-lit globe, so that the outlines of CONTINENTS are projected onto the paper. Usually this projection is used for MAPS of the ARCTIC or ANTARCTIC regions. There is no distortion at the point of tangency or contact, but increased distortion of both shape and area with distance away from the center of the map. Also called a plane projection.

B horizon. SOIL layer just beneath the TOPSOIL.

Backswamp. See BAYOU.

Bajada. See ALLUVIAL FAN.

Bank. Elevated area of land beneath the surface of the OCEAN. The term is also used for elevated ground lining a body of water.

Bar (climate). Measure of ATMOSPHERIC PRESSURE per unit surface area of one million dynes per square centimeter. Millibars (thousandths of a bar) are the MEASUREMENT used in the United States. Other countries use kilopascals (kPa); one kilopascal is ten millibars.

Bar (land). RIDGE or long deposit of SAND or gravel formed by DEPOSITION in a RIVER or at the COAST. Offshore bars and baymouth bars are common coastal features.

Barogram. Chart or record made by a BAROGRAPH.

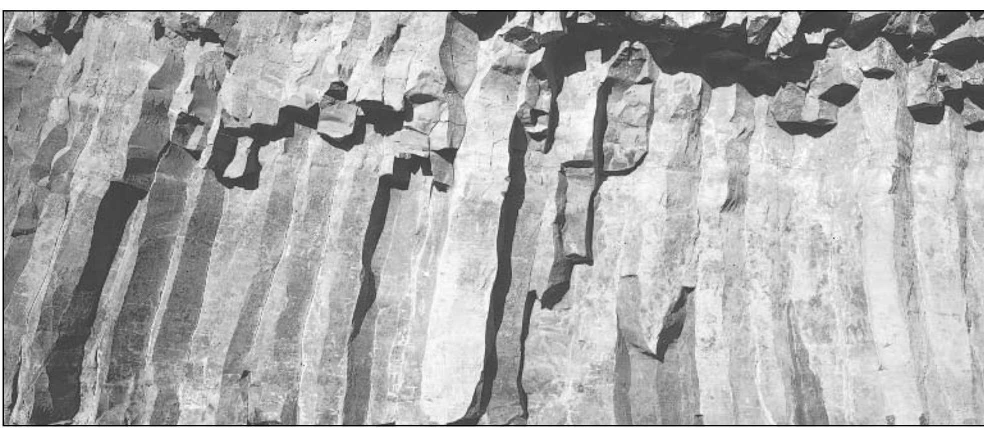
Barograph. BAROMETER that is equipped with a device to provide a continuous record of ATMOSPHERIC PRESSURE.

Barometer. Instrument used for measuring ATMOSPHERIC PRESSURE. In the seventeenth century, Evangelista Torricelli devised the first barometer—a glass tube sealed at one end, filled with mercury, and upended into a bowl of mercury. He noticed how the height of the mercury column changed and realized this was a result of the pressure of air on the mercury in the bowl. Early MEASUREMENTS of atmospheric pressure were, therefore, expressed as centimeters of mercury, with average pressure at SEA LEVEL being 29.92 inches (760 millimeters). This cumbersome barometer was replaced with the ANEROID BAROMETER—a sealed and partially evacuated box connected to a needle and dial, which shows changes in atmospheric pressure. See also ALTIMETER.

Barrier island. Long chain of SAND islands that forms offshore, close to the COAST. LAGOONS or shallower MARSHES separate the barrier islands from the mainland. Such LOCATIONS are hazardous for SETTLEMENTS because they are easily swept away in STORMS and HURRICANES. In the United States, barrier islands extend from the Texas coast to the Outer Banks of North Carolina and on to Long Island. Cape Hatteras is part of the barrier islands, being composed of sand and not part of the mainland.

Barysphere. Dense, heavy CORE of the earth.

Basalt. IGNEOUS EXTRUSIVE ROCK formed when LAVA cools; often black in color. Sometimes basalt occurs in tall hexagonal columns, such as the Giant's Causeway in Ireland, or the Devils Postpile at Mammoth, California.



Basalt cliffs in Yellowstone National Park. An igneous extrusive rock formed when lava cools, basalt is typically black in color. (Corbis)

Base flow. Natural flow of GROUNDWATER into a RIVER, which commonly maintains the flow of PERENNIAL STREAMS during dry seasons.

Base level. Level below which a STREAM cannot erode its bed or VALLEY. For most RIVERS, the ULTIMATE BASE LEVEL is MEAN SEA LEVEL. For rivers that flow into a LAKE, there is a local base level, which is the level of the lake. A section of resistant ROCK might provide a local base level, but this would change through EROSION over time. The base-level concept was developed by John Wesley Powell in the nineteenth century after exploring the Colorado River and Grand Canyon.

Basement. Crystalline, usually PRECAMBRIAN, IGNEOUS and METAMORPHIC ROCKS that occur beneath the SEDIMENTARY ROCK on the CONTINENTS.

Basin. REGION drained by a RIVER system, including all of its tributaries. See also DRAINAGE BASIN.

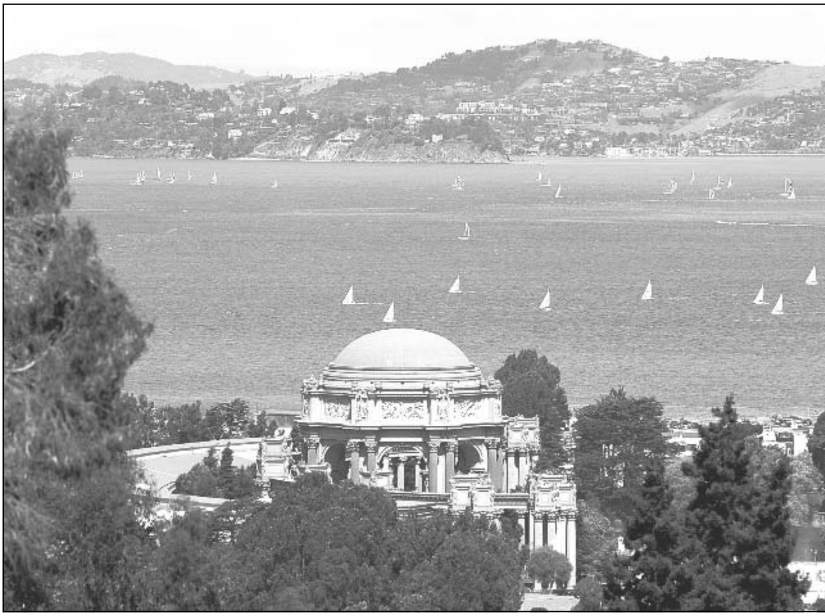
Basin order. Approximate measure of the size of a STREAM BASIN, based on a numbering scheme applied to RIVER channels as they join together in their progress downstream.

Batholith. Large LANDFORM produced by IGNEOUS INTRUSION, composed of CRYSTALLINE ROCK, such as GRANITE; a large PLUTON with a surface area greater than 40 square miles (100 sq. km.). Most mountain RANGES have a batholith underneath.

Fry Creek Batholith in British Columbia. (Geological Survey of Canada)

Bathymetric contour. Line on a MAP of the OCEAN floor that connects points of equal depth.

Bauxite. Principal ORE from which aluminum is obtained. Usually found in the wet TROPICS, although the name comes from a REGION of France.



One of the largest and finest natural harbors in the world is San Francisco Bay, an immense inlet protected from the Pacific Ocean by the San Francisco and Marin peninsulas. (PhotoDisc)

Bay. Part of a SEA or OCEAN partially enclosed by land, such as the Bay of Biscay. "Bay" is not a precise term, but it is usually applied to ocean INLETS smaller than a GULF.

Bayou. Low-lying, swampy area near a RIVER. After a river on a FLOODPLAIN overflows, some water remains, creating a marshy area on either side of the STREAM beyond the NATURAL LEVEES. "Bayou" is a Cajun word. Also called a backswamp.

Beach. Part of a COAST where SEDIMENT has accumulated and is moved by

Honolulu's Waikiki Beach on the Hawaiian island of Oahu is one of the most popular sandy beaches in the world. (PhotoDisc)

WAVES and CURRENTS. The beach zone extends from above the high-tide level to below the low-tide level. Most beaches are covered in SAND; when rounded ROCKS, PEBBLES, or cobbles cover a beach, it is called a shingle beach.

Beaufort scale. SCALE that measures WIND force, expressed in numbers from 0 to 12. The original Beaufort scale was based on descriptions of the state of the SEA. It was adapted to land conditions, using descriptions of chimney smoke, leaves of trees, and similar factors. The scale was devised in the early nineteenth century by Sir Francis Beaufort, a British naval officer.

Bedrock. Solid ROCK covered by SOIL, which is part of the earth's CRUST. When the covering material is removed and the rock exposed at the surface, it is called an OUTCROP.

Belt. Geographical REGION that is distinctive in some way.

Bergeron process. PRECIPITATION formation in COLD CLOUDS whereby ice crystals grow at the expense of supercooled water droplets.

Bight. Wide or open BAY formed by a curve in the COASTLINE, such as the Great Australian Bight.

Billabong. Australian term for a waterhole.

Typical Australian billabong—the kind of waterhole at which the Swagman camped in Australia's unofficial national anthem, "Waltzing Mathilda." (Ray Sumner)

Biodiversity. Measure of the variety of life occupying a particular ECOSYSTEM.

Biogenic sediment. SEDIMENT particles formed from skeletons or shells of microscopic plants and animals living in seawater.

Biogeography. Study of the worldwide DISTRIBUTION of ECOSYSTEMS (plants and animals); also the study of changes in these distributions over time.

Biome. Large ECOSYSTEM on a continental scale; a terrestrial ecosystem. Specific combinations of plants and animals, known as communities, live in each biome.

Biosphere. Parts of Earth in which life exists; includes the lower part of the ATMOSPHERE, the HYDROSPHERE, and the upper LITHOSPHERE (Earth's CRUST). The term is also applied to the complex totality of plant and animal life on Earth.

Biostratigraphy. Identification and organization of STRATA based on their FOSSIL content and the use of fossils in stratigraphic correlation.

Biotechnology. Range of scientific techniques using living tissue, seeds, or organisms to make improved varieties of crops or animals, thereby increasing food production. Biotechnology has led to high-yield, pest-resistant, and DROUGHT-tolerant crops. However, many of the innovations of biotechnology, such as cloning, are controversial. Another issue is that biotechnological research is carried out by MULTINATIONAL CORPORATIONS, whose products are not readily available to the poor RURAL communities whose need for food is greatest. Another fear associated with biotechnology is the security of the world food supply as private firms gain increased control over food production, rather than governments of individual countries.

Birth rate. Annual number of births per one thousand people, in any given POPULATION under study. The birth rate for the United States was fifteen (per thousand per year) at the end of the twentieth century. "Birth rate" is a shortened term for CRUDE BIRTH RATE.

Bitter lake. Saline or BRACKISH LAKE in an arid area, which may dry up in the summer or in periods of DROUGHT. The water is not suitable for drinking. An example is the Bitter Lake Wildlife Refuge in New Mexico, which provides a resting place for huge numbers of migratory birds each year, including Canadian snow geese. Another name for this feature is "salina." See also ALKALI FLAT.

Blizzard. Intense cold STORM in which WINDS reach speeds of at least 35 miles (56 km.) per hour, TEMPERATURES drop below 20 DEGREES Fahrenheit (–7 degrees Celsius), visibility falls below 820 feet (250 meters), and all these conditions last a minimum of three hours. Snowfall often accompanies a blizzard, but this is not a necessary condition; much of the SNOW is simply driven by the strong winds.

Block lava. LAVA flows whose surfaces are composed of large, angular blocks; these blocks are generally larger than those of AA flows and have smooth, not jagged, faces.

Block mountain. MOUNTAIN or mountain RANGE with one side having a gentle slope to the crest, while the other slope, which is the exposed FAULT SCARP, is quite steep. It is formed when a large block of the earth's CRUST is thrust upward on one side only, while the opposite side remains in place. The Sierra Nevada in California are a good example of block mountains. Also known as fault-block mountain.

Blowhole. SEA CAVE or tunnel formed on some rocky, rugged COASTLINES. The pressure of the seawater rushing into the opening can force a jet of seawater to rise or spout through an opening in the roof of the cave. Blowholes are found in Scotland, Tasmania, and Mexico, and on the Hawaiian ISLANDS of Kauai and Maui.

Bluff. Steep slope that marks the farthest edge of a FLOODPLAIN.

Body wave. SEISMIC WAVE that propagates interior to a body; there are two kinds, P WAVES and S WAVES, that travel through the earth, reflecting and refracting off the several layered boundaries within the earth.

Bog. Damp, spongy ground surface covered with decayed or decaying VEGETATION. Bogs usually are formed in cool CLIMATES through the in-filling, or silting up, of a LAKE. Moss and other plants grow outward toward the edge of the lake, which gradually becomes shallower, until the surface is completely covered. Bogs also can form on cold, damp MOUNTAIN surfaces. Many bogs are filled with PEAT.

Bora. Strong, cold, squally downslope WIND on the Dalmatian COAST of Yugoslavia in winter. A KATABATIC WIND.

Border. Technically, the area on either side of a BOUNDARY. The term commonly is used instead of "boundary" to mean the imaginary line separating one COUNTRY from another. The boundary between the United States and Canada, along the forty-ninth PARALLEL north, is the world's longest undefended border.

Bore. Standing WAVE, or wall, of water created in a narrow ESTUARY when the strong incoming, or FLOOD, TIDE meets the RIVER water flowing outward; it moves upstream with the advancing tide, and downstream with the EBB TIDE. South America's Amazon River and Asia's Mekong River have large bores. In North America, the bore in the Bay of Fundy is visited by many tourists each year. Its St. Andrew's wharf is designed to handle changes in water level of as much as 53 feet (15 meters) in one DAY.

Boreal. Alluding to an item or event that is in the NORTHERN HEMISPHERE. Compare with AUSTRAL.

Boreal forest. FORESTS found at LATITUDES above 50 DEGREES north in North America, Europe, and Asia. Because of the intense cold, the trees are needleleaf species, such as spruce and fir. Unlike temperate or tropical forests, boreal forests have little undergrowth; instead, the forest floor is covered with mosses and lichen, which also grow on the tree trunks. Many animals live in the boreal forest, surviving the cold either through MIGRATION or hibernation.

Bottom current. Deep-sea current that flows parallel to BATHYMETRIC CONTOURS.

Bottom-water mass. Body of water at the deepest part of the OCEAN identified by similar patterns of SALINITY and TEMPERATURE.

Boundary. Imaginary line that separates political units from one another. A boundary can be a straight line or a geometric boundary, such as the forty-ninth PARALLEL separating Canada and the United States; other boundaries follow RIVERS, mountain RANGES, or other natural features. People sometimes use the term "BORDER" when speaking about a boundary.

Bourne. English term for a small STREAM OR BROOK. Similar to the Scottish word "burn."

Brackish water. Water with SALT content between that of SALT WATER and FRESH WATER; it is common in arid areas on the surface, in coastal MARSHES, and in salt-contaminated GROUNDWATER.

Brae. Scottish word for the hillside or BANKS of a RIVER.

Braided stream. STREAM having a CHANNEL consisting of a maze of interconnected small channels within a broader STREAMBED. Braiding occurs when the stream's load exceeds its capacity, usually because of reduced flow.

Breaker. WAVE that becomes oversteepened as it approaches the SHORE, reaching a point at which it cannot maintain its vertical shape. It then breaks, and the water washes toward the shore.

A breaker is a wave that becomes oversteepened as it approaches the shore, reaching a point at which it cannot maintain its vertical shape. It then breaks, and the water washes toward the shore. (PhotoDisc)

Breakwater. Large structure, usually of ROCK, built offshore and parallel to the COAST, to absorb WAVE ENERGY and thus protect the SHORE. Between the breakwater and the shore is an area of calm water, often used as a boat anchorage or HARBOR. A similar but smaller structure is a seawall.

Breccia. See CONGLOMERATE.

Breeze. Gentle WIND with a speed of 4 to 31 miles (6 to 50 km.) per hour.

On the BEAUFORT SCALE, the numbers 2 through 6 represent breezes of increasing strength.

Bridge. Physical structure spanning a RIVER, roadway, or other GAP or obstacle. Artificially created bridges are usually used to provide passageways.

Brine. Usually warm, highly saline seawater containing calcium, sodium, potassium, chlorine, and other small amounts of free ions.

Brook. Natural STREAM of water, smaller than a RIVER, issuing from a SPRING.

Bush. Relatively small plant with leafy foliage on several stems that branch close to the ground. The word "shrub" is also used. In Australia, "bush" is a term for any unspecified nonurban area.

Butte. Flat-topped HILL, smaller than a MESA, found in arid REGIONS.

Caldera. Large circular depression with steep sides, formed when a VOLCANO explodes, blowing away its top. The ERUPTION of Mount St. Helens produced a caldera. Crater Lake in Oregon is a caldera that has filled with water. From the Spanish word for kettle.

Caldera. (PhotoDisc)

Calendar. System of dividing time into years, months, and DAYS, based on observations of the SUN, MOON, and stars. The basic unit is the day, which now is measured from one midnight to the next, but often was measured from one DAWN to the next in ancient times. The seven-day week is based on the approximate length of each of the four phases of the Moon. The Julian calendar, with a year length of 365 and one-quarter days, was introduced to the Western world by Julius Caesar in 46 B.C. (The month July commemorates Caesar.) The Julian calendar year was too long by about eleven minutes, so by the sixteenth century the calendar had become out of phase with the SEASONS and religious holidays were falling inappropriately. Pope Gregory XIII, advised by astronomers, determined to omit ten days from the calendar to correct the errors. The Gregorian calendar developed as a result gradually was adopted in other European countries. One of the last countries to adopt it was Russia, in 1918. Ancient peoples had different calendars, and RELIGIONS other than Christianity use different calendars—for example, the year 2000 is 5760 in the Jewish calendar and 1378 in the Muslim calendar.

Calms of Cancer. Subtropical BELT of high pressure and light WINDS, located over the OCEAN near 25 DEGREES north LATITUDE. Also known as the HORSE LATITUDES.

Calms of Capricorn. Subtropical BELT of high pressure and light WINDS, located over the OCEAN near 25 DEGREES south LATITUDE.

Calving. Loss of glacial mass when GLACIERS reach the SEA and large blocks of ice break off, forming ICEBERGS.

Cambrian period. PERIOD from about 570 to 505 million years ago, marked by the appearance of hard-shelled organisms.

Canal. Artificial waterway constructed to shorten the route between two PLACES. Often a canal is cut through an ISTHMUS, as with the Suez Canal and the Panama Canal. Canals also are built to connect two RIVERS, such as the Grand Canal of China, or to bring IRRIGATION water to an arid REGION.

Cancer, tropic of. PARALLEL of LATITUDE at 23.5 DEGREES north; this line is the latitude farthest north on the earth where the noon SUN is ever directly overhead. The REGION between it and the tropic of CAPRICORN is known as the TROPICS.

Canyon. Steep-sided STREAM VALLEY or GORGE in an arid REGION. The

A canyon is steep-sided stream valley or gorge. (PhotoDisc) most famous North American canyon is the Grand Canyon in the southwestern United States.

Cape. Point of land that protrudes beyond the nearby COAST into the SEA or a LAKE. See also HEADLAND.

Capillary water. Water held in the upper part of the SOIL by surface tension of water around the soil particles. See also SOIL MOISTURE.

Capital. CITY that is the seat of a regional or national government.

Capitol. Building that houses a government legislature.

Capricorn, tropic of. Line of LATITUDE at 23.5 DEGREES south; this line is the latitude farthest south on the earth where the noon SUN is ever directly overhead. The REGION between it and the tropic of CANCER is known as the TROPICS.

Carbon cycle. Changes that carbon undergoes in the BIOSPHERE, starting with the conversion by PHOTOSYNTHESIS of atmospheric CARBON DIOXIDE into biomass and its return to a gaseous form during RESPIRATION and decay processes.

Carbon dating. Method employed by physicists to determine the age of organic matter—such as a piece of wood or animal tissue—to determine the age of an archaeological or paleontological SITE. The method works on the principle that the amount of radioactive carbon in living matter diminishes at a steady and measurable rate after the matter dies. Technique is also known as carbon-14 dating, after the radioactive carbon-14 isotope it uses. Also known as radiocarbon dating.

Carbon dioxide. Gas that occurs naturally in the earth's modern ATMOSPHERE, contributing 0.036 percent by volume at the end of the twentieth century. It is produced naturally through RESPIRATION of living organisms and is part of the CARBON CYCLE. The amount of carbon dioxide in the earth's atmosphere has increased over the last two centuries, from 0.028 percent in 1774. This is largely as a result of burning FOSSIL FUELS for ENERGY, which began on a large scale with the INDUSTRIAL REVOLUTION. DEFORESTATION also has contributed to the increased level of carbon dioxide. Because carbon dioxide reflects EARTH RADIATION back to the surface, it is believed to play a large role in GLOBAL WARMING. The United States is the world's largest user of energy and, therefore, the largest producer of carbon dioxide.

Carbonates. Large group of MINERALS consisting of a carbonate anion (three oxygen atoms bonded to one carbon atom, with a residual charge of two) and a variety of cations, including calcium, magnesium, and iron.

Carboniferous period. Fifth of the six PERIODS in the PALEOZOIC ERA; it preceded the PERMIAN PERIOD and spanned a period of 320 to 286 million years ago.

Cardinal points. Four main points of the COMPASS: north, south, east, and west.

Carnivore. Animal that eats mainly flesh. See also FOOD CHAIN.

Carrying capacity. Number of animals that a given area of land can support, without additional feed being necessary. Lush GRASSLAND may have a carrying capacity of twenty sheep per acre, while more arid, SEMIDESERT land may support only two sheep per acre. The term sometimes is used to refer to the number of humans who can be supported in a given area.

Cartography. Specialized science of producing MAPS or CHARTS, which draws on mathematics and art as well as geography. Computer-based cartography developed rapidly at the end of the twentieth century.

Cascade. Series of small WATERFALLS in a rocky part of a STREAMBED.

A cascade is a series of small waterfalls in a rocky part of a stream bed. (PhotoDisc)

Cataract. Large WATERFALL. The Nile River in Africa was impassable to shipping for centuries because of several cataracts.

Catastrophism. Theory, popular in the eighteenth and nineteenth centuries, that explained the shape of LANDFORMS and CONTINENTS and the EXTINCTION of species as the results of intense or catastrophic events.

The biblical FLOOD of Noah was one such event, which supposedly explained many extinctions. Catastrophism is linked closely to the belief that the earth is only about six thousand years old, and therefore tremendous forces must have acted swiftly to create present LANDSCAPES. An alternative or contrasting theory is UNIFORMITARIANISM.

Catchment basin. Area of land receiving the PRECIPITATION that flows into a STREAM. Also called catchment or catchment area.

Causeway. Elevated path or road above water or marshy ground.

Cave. Natural underground opening. Caves commonly form in areas of LIMESTONE ROCK, through SOLUTION of the rock by water. The world's largest system of interconnected caves is in Mammoth Cave National Park in Kentucky. The world's largest single cave is in Sarawak, on the ISLAND of Borneo; the deepest cave is in France. People who explore caves are called speleologists. See also KARST.

Cay. Small ISLANDS or ISLETS of SAND above CORAL REEFS. The term "cay" is used in countries such as Australia; in the United States, they are called KEYS, for example, the Florida Keys.

Celsius scale. TEMPERATURE SCALE devised by Anders Celsius, in which the melting point of ice at SEA LEVEL is zero DEGREES and the boiling point of water at sea level is one hundred degrees. Most countries except the United States use the Celsius scale for temperature MEASUREMENT. The Celsius scale formerly was called the centigrade scale. See also FAHRENHEIT SCALE.

Cenozoic era. PERIOD of geologic time from about 65 million years ago to the present. The youngest of the three PHANEROZOIC EONS, it encompasses two geologic periods, the TERTIARY (older) and the QUATERNARY. Through study of the GEOLOGIC RECORD from this era, scientists are able to distinguish between environmental changes caused by a normal progression of geologic phenomena and those changes that are related to human activity.

Census. Official counting of the POPULATION of a COUNTRY to obtain DEMOGRAPHIC data. The United States takes census every ten years.

Centigrade scale. See CELSIUS SCALE.

Central place theory. Theory that explains why some SETTLEMENTS remain small while others grow to be middle-sized TOWNS, and a few become large cities or METROPOLISES. The explanation is based on the provision of goods and services and how far people will travel to acquire these. The German geographer Walter Christaller developed this theory in the 1930's.

Central places. SETTLEMENTS where goods and services are available to consumers from the surrounding area or REGION. If a PLACE offers few services, the POPULATION will be correspondingly small. From another point of view, small places offer certain essential services, such as a gas station, a convenience store, restaurants, and an elementary school. A larger place offers the previous services, plus perhaps a supermarket, cinema, high school, and post office. Central places are organized hierarchically. There are large numbers of small settlements, relatively closely spaced; there are fewer large cities, located farther apart.

Centrality. Measure of the number of functions, or services, offered by any CITY in a hierarchy of cities within a COUNTRY or a REGION. See also CENTRAL PLACE THEORY.

Centrifugal forces. Forces that divide a COUNTRY. Cultural differences, such as two different LANGUAGES or two different RELIGIONS, are important centrifugal forces. The independence movement in Quebec is a good example of the operation of centrifugal forces. When centrifugal forces outweigh CENTRIPETAL FORCES, a country can break up into smaller units. This process is called DEVOLUTION.

Centripetal forces. Forces that unite a COUNTRY. Cultural characteristics, such as a common LANGUAGE or a single RELIGION, are important centripetal forces. New countries create symbols of unity, such as a national flag and national anthem. A powerful leader can be a strong centripetal force, as can war against a common enemy.

CFC. See CHLOROFLUOROCARBONS.

Chain, island. See ARCHIPELAGO.

Chain, mountain. Another term for mountain RANGE.

Chalk. Naturally occurring sedimentary deposit of soft calcium carbonate. The White Cliffs of Dover are a well-known chalk LANDFORM; EROSION is occurring quickly along that part of the English COAST.

Channel. STREAM channels carry water that falls as PRECIPITATION, or comes from melted SNOW, from one PLACE to another, with the water moving downchannel as a result of GRAVITY. A stream channel changes in width and depth because the volume and speed of the water varies. Channels are usually sinuous, rather than straight. On FLOODPLAINS, the channel becomes a series of MEANDERS. BRAIDED STREAM patterns occur with low flow and high SEDIMENT transport. In arid areas, dry STREAMBEDS (WADIS) are common.

Chaparral. Distinctive shrubland VEGETATION that grows around the SHORES of the Mediterranean Sea (where it is called *maquis*), and in areas of MEDITERRANEAN CLIMATE in California, at the southern tip of South Africa, in central Chile, and in two small REGIONS of western and southern Australia. To adapt to the extreme conditions of a long dry summer and wet winter, plants in this BIOME have small leaves, sometimes with a wax-like coating, and usually have deep root systems. Chaparral regenerates quickly after fire, which is frequent in the summer in the Mediterranean climate.

Chart. MAP indicating dangerous areas, used for NAVIGATION by air and SEA. An aeronautical chart shows MOUNTAINS, towers, and airstrips; a nautical chart shows lighthouses, REEFS, and water depths.

Chemical farming. Application of artificial FERTILIZERS to the SOIL and the use of chemical products such as insecticides, fungicides, and her-

The invention of heavier-than-air flight in the early twentieth century made possible efficient large-scale application of chemical fertilizers with the use of airplanes, popularly known as "crop dusters." (PhotoDisc)

bicides to ensure crop success. Chemical farming is practiced mainly in high-income countries, because the cost of the chemical products is high. Farmers in low-income economies rely more on natural organic fertilizers such as animal waste.

Chemical weathering. Chemical decomposition of solid ROCK by processes involving water that change its original materials into new chemical combinations.

Chinook. Warm WIND that melts SNOWS on the Canadian PRAIRIES, enabling farmers to plow and plant their spring wheat. A Chinook originates as AIR descends on the eastern or LEEWARD side of the Rocky

Mountains. Having lost all its moisture on the WINDWARD side, this is a dry wind that warms ADIABATICALLY as it descends. The wind is welcomed by farmers and is sometimes called the "snow-eater." In Europe, similar winds are called FÖHN.

Chlorofluorocarbons (CFCs). Manufactured compounds, not occurring in nature, consisting of chlorine, fluorine, and carbon. CFCs are stable and have heat-absorbing properties, so they have been used extensively for cooling in refrigeration and air-conditioning units. Previously, they were used as propellants for aerosol products. CFCs rise into the STRATOSPHERE where ULTRAVIOLET RADIATION causes them to react with OZONE, changing it to oxygen and exposing the earth to higher levels of ultraviolet (UV) radiation. Therefore, the manufacture and use of CFCs was banned in many countries. The commercial name for CFCs is Freon.

Chorology. Description or mapping of a REGION. Also known as chorography.

Chronometer. Highly accurate CLOCK or timekeeping device. The first accurate and effective chronometers were constructed in the mid-eighteenth century by John Harrison, who realized that accurate timekeeping was the secret to NAVIGATION at SEA.

Chubasco. Type of severe STORM that occasionally occurs in the Gulf of California and along the west COAST of Mexico.

Cinder cone. Small conical HILL produced by PYROCLASTIC materials from a VOLCANO. The material of the cone is loose SCORIA.

Volcanic cinder cones on the island of Hawaii. (Corbis)

Circle of illumination. Line separating the sunlit part of the earth from the part in darkness. The circle of illumination moves around the earth once in every approximately 24 hours. At the VERNAL and autumnal EQUINOXES, the circle of illumination passes through the POLES.

Washington State's Wenatchee Mountains contain remnants of old alpine glaciers, which surround Mount Stuart; these include U-shaped valleys and four small cirque glaciers in the shadows. (U.S. Geological Survey)

Cirque. Circular BASIN at the head of an ALPINE GLACIER, shaped like an armchair. Many cirques can be seen in MOUNTAIN areas where glaciers have completely melted since the last ICE AGE.

Cirro. Prefix meaning high CLOUDS, from the Latin word *cirrus,* meaning a lock of hair.

Cirrocumulus. High, thin, puffy white CLOUDS of ice crystals that look like ripples. They appear between 20,000 and 40,000 feet (6,000-12,000 meters) above the earth's surface. One type of cirrocumulus cloud is called a "mackerel sky," because the clouds resemble large fish scales, especially when they are colored pink at SUNSET.

Cirrostratus. Semitransparent sheets of CLOUD, comprising layers of thin ice crystals. They appear between 20,000 and 40,000 feet (6,000-12,000 meters) above the earth's surface. A halo around the MOON can be caused by cirrostratus clouds.

Cirrus. High, wispy tufts of CLOUDS, white but almost transparent because they are composed mostly of ice crystals. Formed at a height of 20,000 to 30,000 feet (6,000-9,000 meters). Cirrus clouds can indicate an approaching COLD FRONT. Sometimes called "mares' tails." The prefix *cirro* is added to shape words to define two other kinds of high clouds—CIRROCUMULUS and CIRROSTRATUS.

City Beautiful movement. Planning and architectural movement that was at its height from around 1890 to the 1920's in the United States. It was believed that classical architecture, wide and carefully laid-out streets, parks, and urban monuments would reflect the higher values of the society and be a civilizing, even uplifting, experience for the citizens of such cities. Civic pride was fostered through remodeling or modernizing older URBAN AREAS. Chicago, Illinois, and Pasadena, California, are cities where the planners of the City Beautiful movement left their imprint.

City. Generally large human SETTLEMENTS in which nonagricultural occupations dominate. In the United States, a city is technically defined as an incorporated MUNICIPALITY with definite boundaries and legal powers set forth in a charter granted by the STATE. Since 1910 the U.S. Census Bureau has recognized any PLACE with more than twenty-five hundred inhabitants as URBAN. In the United Kingdom, cities were historically defined not by their POPULATION sizes, but on the basis of their religious status: whether they had cathedrals with bishops.

Civilization. Type of CULTURE or society comprising urban POPULATIONS, RELIGION, architecture, and formalized methods of passing on learning. The AGRICULTURAL REVOLUTION, when human societies began growing crops instead of relying on HUNTING AND GATHERING, enabled the earliest civilizations to emerge more than six thousand years ago, in Mesopotamia.

Clastic. ROCK or sedimentary matter formed from fragments of older rocks.

Clay. Finely grained SOIL. Soils that are largely clay are generally unsuitable for AGRICULTURE because they are impermeable to plant roots. Soils known as cracking clays, or vertisols, can absorb large amounts of water, which causes them to swell as they expand, but cracks as large as three feet (1 meter) deep open as the soil dries out. These clays are found in Texas and over large REGIONS in eastern Australia, India, and tropical East Africa.

Clearing. Open part of a FOREST where trees and other VEGETATION have been removed, often for farming.

Cliff. Hillslope that is nearly vertical.

Climagraph. See CLIMOGRAPH.

Climate. Long-term conditions of TEMPERATURE and PRECIPITATION for a PLACE over a period of not less than thirty years. Climate takes account of variability and extremes to give a composite picture of a climate type or a climate REGION. Climate is not exactly the same as WEATHER, which is the situation of the ATMOSPHERE at any moment, and thus changes constantly.

Climatology. Study of Earth CLIMATES by analysis of long-term WEATHER patterns over a minimum of thirty years of statistical records. Climatologists—scientists who study climate—seek similarities to enable grouping into climatic REGIONS. Climate patterns are closely related to natural VEGETATION. Computer TECHNOLOGY has enabled investigation of phenomena such as the EL NIÑO effect and global climate change. The KOEPPEN CLIMATE CLASSIFICATION system is the most commonly used scheme for climate classification.

Climograph. Graph that plots TEMPERATURE and PRECIPITATION for a selected LOCATION. The most commonly used climographs plot monthly temperatures and monthly precipitation, as used in the KOEPPEN CLIMATE CLASSIFICATION. Also spelled "climagraph." The term climagram is rarely used.

Clinometer. Instrument used by surveyors to measure the ELEVATION of land or the inclination (slope) of the land surface.

Clock. Machine that measures time and displays the result continuously. An especially accurate clock or timekeeper is called a CHRONOMETER.

Clockwise. Rotating direction matching that of the hands on a CLOCK dial when viewed from the same perspective. This term and its opposite, COUNTERCLOCKWISE, are often used to describe the movements of WEATHER phenomena and the ROTATIONS of celestial objects.

Cloud. Atmospheric occurrence of moisture droplets and ice crystals suspended in AIR. Particles such as DUST or smoke may also be present. Clouds are classified according to their shapes and heights. The classification, and the words used, were proposed by English scientist Luke Howard in the early nineteenth century. See ALTOCUMULUS; ALTOSTRATUS; CIRROCUMULUS; CIRROSTRATUS; CIRRUS; CUMULONIMBUS; CUMULUS.

Cloud cover. Amount of the sky that is covered with CLOUD, shown on a WEATHER MAP by shading parts of a circle. If the sky is half-covered, the right half of the circle is shaded.

Cloud cover is the amount of sky covered with clouds. On weather maps, it is shown by shading parts of a circle. When the sky is half-covered, the right half of the circle is shaded. (PhotoDisc)

Cloud-free. Having less than 30 percent CLOUD COVER, allowing clear imaging of a surface area.

Cloud seeding. Injection of CLOUD-nucleating particles into likely clouds to enhance PRECIPITATION.

Cloudburst. Heavy rain that falls suddenly.

Coal. One of the FOSSIL FUELS. Coal was formed from fossilized plant material, which was originally FOREST. It was then buried and compacted, which led to chemical changes. Most coal was formed during the CARBONIFEROUS PERIOD (286 million to 360 million years ago) when the earth's CLIMATE was wetter and warmer than at present.

Coast. Land above the high-tide level where land meets the OCEAN. The coast is a PLACE of constant change, due to natural changes, such as varying SEA LEVEL OR TECTONIC movements, as well as human activities, such as constructing PORT facilities, marinas, and housing developments.

Coastal plain. Large area of flat land near the OCEAN. Coastal plains can form in various ways, but FLUVIAL DEPOSITION is an important process. In the United States, the coastal plain extends from Texas to North Carolina.

Coastal wetlands. Shallow, wet, or flooded shelves that extend back from the freshwater-saltwater interface and may consist of MARSHES, BAYS, LAGOONS, tidal flats, or MANGROVE SWAMPS.

Coastline. Specific line of contact between land and SEA. The coastline changes constantly because of TIDES, STORMS, and sea-level changes. Also called SHORELINE.

Cognitive map. Mental image that each person has of the world, which includes LOCATIONS and connections. These maps expand as children mature, from plans of their rooms, to their houses, to their neighborhoods. Adults know certain parts of the CITY and the streets connecting them. See also MENTAL MAP.

Coke. Type of fuel produced by heating COAL.

Col. Lower section of a RIDGE, usually formed by the headward EROSION of two CIRQUE GLACIERS at an ARÊTE. Sometimes called a saddle.

Cold cloud. Visible SUSPENSION of tiny ice crystals, supercooled water droplets, or both at sub-freezing TEMPERATURES.

Cold front. FRONT or leading edge of an advancing cold AIR mass that displaces warmer air as it moves. On a WEATHER MAP, a cold front is shown by a line of triangular "shark teeth" pointing in the direction of advance. A cold front is accompanied by STORMS and rain.

Cold War. Period that lasted from the end of World War II, in 1945, until the collapse of the Soviet Union, in 1991, during which the communist NATIONS of the East and the noncommunist nations of the West competed for world supremacy and engaged in military buildups in anticipation of a new global war.

Cold wave. Sudden onset of extremely cold WEATHER, with TEMPERATURE below freezing, the change taking less than twenty-four hours.

Colonial cities. Cities established and developed by colonial governments to serve as administrative or commercial centers. Some colonial cities were newly created in a LOCATION where there was previously no URBAN SETTLEMENT. The colonial power laid out a new planned CITY with ceremonial buildings and PLACES, offices, administrative headquarters, commercial facilities, and military barracks. Local people came to the new colonial city to serve in low-paid service jobs such as clerks and servants. Colonial cities of this kind include Calcutta, Nairobi, Hong Kong, and Jakarta. A different type of colonial city arose through the addition of colonial functions to an already established settlement. There, source of labor and considerable SITE advantages already existed. Mexico City, Delhi, and Shanghai are examples of this kind of colonial city. Most colonial cities were located on the COAST, for ease of access to shipping goods back to the European colonial power.

Colonialism. Control of one COUNTRY over another STATE and its people. Many European countries have created colonial empires, including Great Britain, France, Spain, Portugal, the Netherlands, and Russia.

Colony. COUNTRY that is a political DEPENDENCY of another NATION. During the early twentieth century, most of the countries of Africa, the Pacific, and the Caribbean, as well as many in Asia, were colonies of European powers. By the beginning of the twenty-first century, however, few colonies remained in the world.

Columbian exchange. Interaction that occurred between the Americas and Europe after the voyages of Christopher Columbus. Food crops from the New World transformed the diet of many European countries.

Combe. Welsh word for the uppermost part of a VALLEY, above the springline. Also called coombe.

Comet. Small body in the SOLAR SYSTEM, consisting of a solid head with a long gaseous tail. The elliptical ORBIT of a comet causes it to range

The most famous of the many comets that pass through the Solar System is Halley's, which made its last transit near Earth in 1986. (PhotoDisc) from very close to the SUN to very far away. In ancient times, the appearance of a comet in the sky was thought to be an omen of great events or changes, such as war or the death of a king.

Comfort index. Number that expresses the combined effects of TEMPERATURE and HUMIDITY on human bodily comfort. The index number is obtained by measuring ambient conditions and comparing these to a chart.

Commodity chain. Network linking labor, production, delivery, and sale for any product. The chain begins with the production of the raw material, such as the extraction of MINERALS by miners, and extends to the acquisition of the finished product by a consumer.

Communications. Systems used to transmit messages or information from one PLACE to another; now systems such as the Internet, telephones, television, and mail.

Communities, animal or plant. See BIOME.

Compass, magnetic. Instrument that determines direction, used for NAVIGATION. A magnetic needle is mounted so that it can rotate and align its ends with the earth's MAGNETIC FIELD. A naturally occurring ORE of iron called lodestone aligns in a north-south direction; a piece of iron, placed in contact with the lodestone, becomes magnetized and also aligns itself this way. The magnetic compass has been used since the twelfth century, both in Europe and in China. The earliest compasses consisted of a magnetized needle that floated in a bowl of water. Soon a card with the points of the compass was added to the compass, so that readings could be made quickly and simply. When ships were built of iron in the nineteenth century, many adaptations had to be made to maintain the accuracy of the magnetic compass.

Complex crater. IMPACT CRATER of large diameter and low depth-to-diameter ratio caused by the presence of a central UPLIFT or ring structure.

Composite cone. Cone or VOLCANO formed by volcanic explosions in which the LAVA is of different composition, sometimes fluid, sometimes PYROCLASTS such as cinders. The alternation of layers allows a concave shape for the cone. These are generally regarded as the world's most beautiful volcanoes. Composite volcanoes are sometimes called STRATOVOLCANOES.

Condensation. Process in which water changes from a vapor state to a liquid state, releasing heat into the surrounding AIR; this process is the opposite of EVAPORATION, which requires the input of heat. Water VAPOR condenses into DEW, FOG, or CLOUD droplets.

Condensation nuclei. Microscopic particles that may have originated as DUST, soot, ASH from fires or VOLCANOES, or even SEA SALT; an essential part of CLOUD formation. When AIR rises and cools to the DEW POINT (saturation), the moisture droplets condense around the nuclei, leading to the creation of raindrops or snowflakes. A typical air mass might contain ten billion condensation nuclei in a single cubic yard (1 cubic meter) of air.

Cone, volcanic. See CINDER CONE; COMPOSITE CONE.

Cone of depression. Cone-shaped depression produced in the WATER TABLE by pumping from a WELL.

Confined aquifer. AQUIFER that is completely filled with water and whose upper BOUNDARY is a CONFINING BED; it is also called an artesian aquifer.

Confining bed. Impermeable layer in the earth that inhibits vertical water movement.

Confluence. PLACE where two STREAMS or RIVERS flow together and join. The smaller of the two streams is called a TRIBUTARY.

Conglomerate. Type of SEDIMENTARY ROCK consisting of smaller rounded fragments naturally cemented together by another MINERAL. If the cemented fragments are jagged or angular, the rock is called breccia.

Conglomerate corporation. Large, transnational corporation whose operations cover a diverse range of economic activities. Generally created by mergers and acquisitions; one of the effects of globalization of industry and TRADE. United States' names dominate the conglomerates: Phillip Morris expanded from tobacco into foods, beer, real estate, and publishing. Nestlé, based in Switzerland, sells many food products, pet food, wine, and cosmetics, and also has interests in the hotel business.

Conical projection. MAP PROJECTION that can be imagined as a cone of paper resting like a witch's hat on a globe with a light source at its center; the images of the CONTINENTS would be projected onto the paper. In reality, maps are constructed mathematically. A conic projection can show only part of one HEMISPHERE. This projection is suitable for constructing a MAP of the United States, as a good EQUAL-AREA representation can be achieved. Also called conic projection.

Coniferous forest. FOREST type found naturally growing in cool CLIMATES with sufficient PRECIPITATION, throughout most of Canada and

Coniferous forests are found naturally growing in cool climates with at least moderate precipitation. (PhotoDisc) extensive areas of Russia, where it is called TAIGA. The trees are needleleaf species of pine, fir, spruce, and larch. BOREAL FOREST is another name for this BIOME. The trees are valuable sources of lumber for construction or pulpwood for newspaper production. Needleleaf forests also occur in mountainous REGIONS, as in parts of the Rocky Mountains, Sierra Nevada, European Alps, and Himalayas.

Consequent river. RIVER that flows across a LANDSCAPE because of GRAVITY. Its direction is determined by the original slope of the land. TRIBUTARY streams, which develop later as EROSION proceeds, are called subsequent streams.

Conservationism. Practice of protecting natural things from loss or damage—from a stand of trees to the earth's ENVIRONMENT as a whole. SOIL conservation deals with preventing the loss of valuable TOPSOIL through poor agricultural practices. Open space conservation leads to the creation of parkland reserves around and sometimes within cities. Many international and other organizations are involved in conservation of RESOURCES such as RAIN FORESTS, plant and animal species, and natural areas.

Contaminant. Any ion or chemical that is introduced into the ENVIRONMENT, especially in concentrations greater than those normally present.

Continent. Principal LANDMASSES of the earth, comprising Eurasia, Africa, North America, South America, Antarctica, and Australia. The continents cover approximately one-quarter of the earth's surface at present sea-level conditions, accounting for an area of almost 60 million square miles (150 million sq. km.). The continental shelves, which are now under water, are geologically part of the continents; if this total area were measured, the continents would account for about one-third of the earth's surface. These continents are based on a physical definition, but many people use a cultural distinction, and thus divide Eurasia into two continents—Asia and Europe—because there are marked cultural differences between peoples of the two parts of this single landmass. Throughout geologic time, the continents have been joined and separated many times. See also PLATE TECTONICS.

Continental climate. CLIMATE experienced over the central REGIONS of large LANDMASSES; drier and subject to greater seasonal extremes of TEMPERATURE than at the CONTINENTAL MARGINS.

Continental crust. Earth's CRUST consists of two different types of ROCKS: continental crust and OCEANIC CRUST. Continental crust is crystalline, and lighter in weight than the denser oceanic crust. GRANITE is the most abundant rock of the continental crust. An older term for continental crust was "SIAL."

Continental divide. High REGION that separates DRAINAGE on a continental scale. In North America, the Continental Divide separates RIVERS flowing west to the Pacific Ocean from those flowing south and east to the Atlantic Ocean or north to the Arctic Ocean.

Continental drift. Theory, proposed in 1912 by German scientist Alfred Wegener, holding that the CONTINENTS of the earth have changed position continuously over the past 225 million years. Wegener hypothesized the existence of an ancient SUPERCONTINENT, which he named PANGAEA, that slowly broke apart as its component continents drifted into their present positions. Although the theory was not initially accepted in English-speaking countries, it became the influential theory of PLATE TECTONICS.

Continental glaciers. Continental glaciers once covered much of northern North America and Europe, but now only Greenland and Antarctica have such huge masses of permanent ice and SNOW. Because continental glaciers are so large, they affect the CLIMATE of large REGIONS outside their boundaries by lowering AIR and water TEMPERATURES. Continental glaciers of past ICE AGES have produced a wide variety of erosional and depositional features in northern LATITUDES.

Continental island. ISLAND that is part of the CONTINENTAL SHELF, rising above SEA LEVEL. Such islands are actually part of their adjacent CONTINENTS, with the same compositions as their nearby continents. They have become separated from the continents as a result of TECTONIC movement over thousands of years. Their ROCK types are consistent with the mainland. Most of the world's large islands are continental islands. For example, Greenland is a continental island of North America, New Guinea is a continental island of Australia, and Madagascar is a continental island of Africa. In contrast, OCEANIC ISLANDS, such as Hawaii, rise from the OCEAN floor. Some continental islands are located close to the COAST and have become separated only since sea level rose over the last several thousand years. Tasmania is an example of this kind of continental island. These continental islands are called high islands.

Continental margin. COASTLINE and BEACHES, plus the CONTINENTAL SHELF and continental rise. Continental margins make up about 20 percent of the OCEAN but are the most valuable part because of land values onshore and fishing in the shallow waters just offshore. According to the theory of PLATE TECTONICS, continental margins can be passive, when there is no obvious movement of the margin, although it is being moved with the PLATE; at an active continental margin, in contrast, motion is obvious. The continental margin of California, Oregon, and Washington is an active continental margin, where TRANSFORM MOTION is occurring with SUBDUCTION occurring to the north of this.

Continental rift zones. Continental rift zones are PLACES where the CONTINENTAL CRUST is stretched and thinned. Distinctive features include active VOLCANOES and long, straight VALLEY systems formed by normal FAULTS. Continental rifting in some cases has evolved into the breaking apart of a CONTINENT by SEAFLOOR SPREADING to form a new OCEAN.

Continental shelf. Shallow, gently sloping part of the seafloor adjacent to the mainland. The continental shelf is geologically part of the CONTINENT and is made of CONTINENTAL CRUST, whereas the OCEAN floor is OCEANIC CRUST. Although continental shelves vary greatly in width, on average they are about 45 miles (75 km.) wide and have slopes of 7 minutes (about one-tenth of a DEGREE). The average depth of a continental shelf is about 200 feet (60 meters). The outer edge of the continental shelf is marked by a sharp change in angle where the CONTINENTAL SLOPE begins. Most continental shelves were exposed above current SEA LEVEL during the PLEISTOCENE EPOCH and have been submerged by rising sea levels over the past eighteen thousand years.

Continental shield. Area of a CONTINENT that contains the oldest ROCKS on Earth, called CRATONS. These are areas of granitic rocks, part of the CONTINENTAL CRUST, where there are ancient MOUNTAINS. The Canadian Shield in North America is an example.

Continental slope. Part of the OCEAN floor between the outer edge of the CONTINENTAL SHELF and the DEEP seafloor of the OCEAN BASINS. Although there is great variation, the continental slope on average is about 12 miles (20 km.) in width and has an average slope of 4 DEGREES; it extends from a water depth of about 425 feet (130 meters) below SEA LEVEL to somewhere between 5,000 and 10,000 feet (1,400-3,000 meters) deep.

Contour lines. Lines on a TOPOGRAPHIC MAP that join PLACES of equal ELEVATION. A series of contour lines reveals the overall shape and elevation of TERRAIN.

Convection. Transfer of heat from a source area to a point farther away through vertical motion and subsequent spreading, as in the vertical AIR circulation in which warm air rises and cool air sinks.

Convectional rain. Type of PRECIPITATION caused when AIR over a warm surface is warmed and rises, leading to ADIABATIC cooling, CONDENSATION, and, if the air is moist enough, rain.

Convective overturn. Renewal of the bottom waters caused by the sinking of SURFACE WATERS that have become denser, usually because of decreased TEMPERATURE.

Convergence (climate). AIR flowing in toward a central point.

Convergence (physiography). Process that occurs during the second half of a SUPERCONTINENT CYCLE, whereby crustal PLATES collide and intervening OCEANS disappear as a result of plate SUBDUCTION.

Convergent plate boundary. Compressional PLATE BOUNDARY at which an oceanic PLATE is subducted or two continental plates collide.

Convergent plate margin. Area where the earth's LITHOSPHERE is returned to the MANTLE at a SUBDUCTION ZONE, forming volcanic "ISLAND ARCS" and associated HYDROTHERMAL activity.

Conveyor belt current. Large CYCLE of water movement that carries warm water from the north Pacific westward across the Indian Ocean, around Southern Africa, and into the Atlantic, where it warms the ATMOsphere, then returns at a deeper OCEAN level to rise and begin the process again.

Coombe. See COMBE.

Coordinated universal time (UTC). International basis of time, introduced to the world in 1964. The basis for UTC is a small number of ATOMIC CLOCKS. Leap seconds are occasionally added to UTC to keep it synchronized with universal time.

Copse. English term for a small area where the VEGETATION consists of small trees and thick shrubs or BUSHES. An older word is "coppice."

Coral reef. LIMESTONE structure found in shallow tropical SEAS, consisting of a living biological community atop the calcium carbonate remains of many generations of dead coral. Individual coral polyps are tiny, but their accreted skeletons can form huge RIDGES or REEFS. Depending on LOCATION, reefs are classified into four types—FRINGING REEFS, barrier reefs, ATOLLS, and patch reefs. The world's largest coral reef is the Great Barrier Reef, off the east COAST of northern Australia. Reefs also are found in Florida and around many ISLANDS of the Pacific and Indian Oceans.

The Florida Keys comprise small sandy islands built up by wave action on coral reefs. (Visit Florida)

Cordillera. Large mountain CHAIN such as the Rocky Mountains in North America or the Andes Mountains in South America. "Cordilleran system" denotes this group of relatively young mountains, extending from Alaska in the north to Tierra del Fuego in the south.

Core. Innermost part of the earth, believed to comprise two distinct zones. The OUTER CORE is dense, molten, and mostly iron, and is responsible for the earth's MAGNETIC FIELD; the INNER CORE is thought to be solid and mostly iron.

Core-mantle boundary. SEISMIC discontinuity 1,790 miles (2,890 km.) below the earth's surface that separates the MANTLE from the OUTER CORE.

Core region. Area, generally around a COUNTRY'S CAPITAL CITY, that has a large, dense POPULATION and is the center of TRADE, financial services, and production. The rest of the country is referred to as the PERIPHERY. On a larger scale, the CONTINENT of Europe has a core region, which includes London, Paris, and Berlin; Iceland, Portugal, and Greece are peripheral LOCATIONS.

Coriolis effect. Apparent deflection of moving objects above the earth because of the earth's ROTATION. The deflection is to the right in the NORTHERN HEMISPHERE and to the left in the SOUTHERN HEMISPHERE. The deflection is inversely proportional to the speed of the earth's rotation, being negligible at the EQUATOR but at its maximum near the POLES. The Coriolis effect is a major influence on the direction of surface WINDS. Sometimes called Coriolis force.

Corn Belt. Part of the United States covering Iowa, Illinois, and Indiana, and parts of Minnesota, South Dakota, Nebraska, Minnesota, and Ohio. A REGION of mixed crop-and-LIVESTOCK AGRICULTURE, where corn growing and hog farming are combined on farms. Corn is also used at feedlots to fatten cattle from areas farther west. The main agricultural product of the Corn Belt, therefore, is meat.

Corrasion. EROSION and lowering of a STREAMBED by FLUVIAL action, especially by ABRASION of the bedload (material transported by the STREAM) but also including SOLUTION by the water.

Cosmogony. Study of the origin and nature of the SOLAR SYSTEM.

Cosmopolitanism. Intellectual openness to a variety of CULTURES, experiences, and products from other REGIONS or countries. Previously, people gained a cosmopolitan perspective mainly through travel to foreign countries, but now television, motion pictures, and the Internet can bring aspects of foreign contemporary cultures directly to consumers in their own homes.

Cotton Belt. Part of the United States extending from South Carolina through Georgia, Alabama, Mississippi, Tennessee, Louisiana, Arkansas, Texas, and Oklahoma, where cotton was grown on PLANTATIONS using slave labor before the Civil War. After that war, the South stagnated for almost a century. Racial SEGREGATION contributed to cultural isolation from the rest of the United States. Cotton is still produced in this REGION, but California has overtaken the Southern STATES as a cotton producer, and other agricultural products, such as soybeans and poultry, have become dominant crops in the old Cotton

Belt. In-migration, due to the SUN BELT attraction, has led to rapid urban growth in the old Cotton Belt..

Counterclockwise. Rotating direction opposite to that of the hands on a CLOCK dial when viewed from the same perspective. This term and its opposite, CLOCKWISE, are often used to describe the movements of WEATHER phenomena and the ROTATIONS of celestial objects. For example, low-pressure areas are characterized by WINDS moving in a counterclockwise direction in the NORTHERN HEMISPHERE.

Counterurbanization. Out-migration of people from URBAN AREAS to smaller TOWNS or RURAL areas. As large modern cities are perceived to be overcrowded, stressful, polluted, and dangerous, many of their residents move to areas they regard as more favorable. Such moves are often related to individuals' retirements; however, younger workers and families are also part of counterurbanization.

Country. Commonly used to mean an independent and sovereign STATE, such as the United States, Canada, or Germany; a NATION-STATE. Also used to mean RURAL, as compared with a TOWN or CITY, as in "country roads" or "country cousins."

County. Unit into which some countries are subdivided for local administration. In the United States, the level below the STATE government (called PARISHES in Louisiana). In the United Kingdom, the level of major division for administration, similar to the states of the United States.

County seat. CITY or TOWN containing the administrative headquarters of the surrounding COUNTY.

Cove. Small opening in the COASTLINE of any larger body of water. A cove can be a small BAY, usually well protected by HEADLANDS.

Crag. Scottish and Welsh word for a steep, rocky CLIFF in the MOUNTAINS or on coastal HEADLANDS and ISLANDS.

Crater. Circular depression at the top of a VOLCANO, from which molten material emerges. Craters also are found on the flanks of larger volcanoes.

Wizard Island in Oregon's Crater Lake. The lake fills the caldera of a volcano that erupted about 76,000 years ago. After the volcano emptied itself, it collapsed into its own hole to create the caldera. (Corbis)

Crater morphology. Structure or form of CRATERS and the related processes that developed them.

Craton. Large, geologically old, relatively stable CORE of a continental LITHOSPHERIC PLATE, sometimes termed a CONTINENTAL SHIELD.

Creep. Slow, gradual downslope movement of SOIL materials under gravitational stress. Creep tests are experiments conducted to assess the effects of time on ROCK properties, in which environmental conditions (surrounding pressure, TEMPERATURE) and the deforming stress are held constant.

Crestal plane. Plane or surface that goes through the highest points of all beds in a fold; it is coincident with the axial plane when the axial plane is vertical.

Cretaceous era. Third, last, and longest geologic PERIOD of the MESOZOIC ERA, 144 million to 65 million years ago. During the era SEAS covered much of North America and the Rocky Mountains were formed. The end of the era was marked by the EXTINCTION of the dinosaurs.

Inside a crevasse in Blue Ice Valley on the Greenland ice sheet, sixty-five feet below the surface. (U.S. Geological Survey)

Crevasse. Deep vertical crack that forms in a GLACIER as a result of stresses. Fresh snowfall can cover a crevasse, making glacier exploration hazardous.

Crop rotation. Agricultural practice of growing alternating crops on the same field. Generally a LEGUME, such as alfalfa or clover, is grown as a fodder crop after a grain crop has been grown for one or two years. The legume helps restore soil fertility by adding nitrogen. Crop rotation was developed in the late seventeenth century in Europe, as one of a series of advances known as the AGRICULTURAL REVOLUTION.

Cross-bedding. Layers of ROCK or SAND that lie at an angle to horizontal bedding or to the ground.

Crown land. Land belonging to a NATION'S MONARCHY. Some parts of crown land are used as public parks; others are leased and used for private agriculture or other commercial purposes.

Crude birth rate. Ratio of the number of live births in a COUNTRY in a single year for every thousand people of the total POPULATION. In high-income economies, the crude birth rate is less than twenty. In the United States in 2000, it was fifteen per thousand. In some African countries, such as Somalia, it was fifty per thousand.

Crude death rate. Ratio of the number of deaths in a COUNTRY in a single year for every thousand people of the total POPULATION. When the CRUDE BIRTH RATE is higher than the crude death rate, the population of a country is increasing assuming that there is no net MIGRATION loss. In the United States in 2000, the crude death rate was nine per thousand. The difference between the crude birth rate and the crude death rate is the rate of NATURAL INCREASE, which is expressed as a percentage. For the United States in 2000, the rate of natural increase was 0.6 percent (six per thousand).

Crude oil. Unrefined OIL, as it occurs naturally. Also called PETROLEUM.

Crust. Outer layer of the earth, made of crystalline ROCKS and varying in thickness from 3 miles (5 km.) beneath the OCEANS to 38 miles (60 km.) under the continental mountain RANGES. It consists of rocky material which is less dense than the MANTLE.

Crustal movements. PLATE TECTONICS theorizes that Earth's CRUST is not a single rigid shell, but comprises a number of large pieces that are in motion, separating or colliding. There are two types of crust—the older continental and the much younger OCEANIC CRUST. When PLATES diverge, at SEAFLOOR SPREADING zones, new (oceanic) crust is created from the MAGMA that flows out at the MID-OCEAN RIDGES. When plates converge and collide, denser oceanic crust is SUBDUCTED under the lighter CONTINENTAL CRUST. The boundaries at the areas where plates slide laterally, neither diverging nor converging, are called TRANSFORM FAULTS. The San Andreas Fault represents the world's best-known transform BOUNDARY. As a result of crustal movements, the earth can be deformed in several ways. Where PLATE BOUNDARIES converge, compression can occur, leading to FOLDING and the creation of SYNCLINES and ANTICLINES. Other stresses of the crust can lead to fracture, or faulting, and accompanying EARTHQUAKES. LANDFORMS created in this way include HORSTS, GRABEN, and BLOCK MOUNTAINS.

Cuesta. Spanish term used to describe an ESCARPMENT and its associated gentle dip slope, formed in SEDIMENTARY ROCKS.

Cultural ecology. Study of the interaction between humans and their ENVIRONMENT; for example, the study of how human societies have adapted to certain physical conditions, such as prolonged cold in northern Canada or arid conditions in northern Mexico. Cultural ecology is related to cultural anthropology. In highly urbanized societies, cultural ecologists study how people shape their URBAN environments and how those environments affect human lifestyle and behavior.

Cultural geography. Study of how LANDSCAPES, space, and PLACE shape various CULTURES, while at the same time different cultures shape and influence the landscapes, spaces, and places.

Cultural landscape. Evidence of the effect of human activities on the natural LANDSCAPE.

Cultural nationalism. Movement that has grown rapidly in the face of globalization. Modern media have a homogenizing effect on national and regional CULTURES. Governments, and some smaller groups, have attempted to protect and preserve their culture from globalization, which has often meant Americanization. Some measures adopted have included negative acts such as restricting the broadcast of American programs on television and banning certain recordings of videocassettes; positive measures include promotion of literature in the national LANGUAGE or regional DIALECT, investment in local cultural and artistic productions, and the creation of archives, oral histories, and museums.

Culture. In anthropology, the learned parts of human behavior that are transmitted through generations. Culture includes LANGUAGE, RELIGION, foods and their preparation, clothing, ceremonies, housing, and the other factors that are shared by a cultural group. Geographers are concerned with how any particular culture, or way of life, is related to the physical LANDSCAPE. They also study how cultures vary from one PLACE to another and how cultures change over time.

Culture hearth. LOCATION in which a CULTURE has developed; a CORE REGION from which the culture later spread or diffused outward through a larger REGION. Mesopotamia, the Nile Valley, and the Peruvian ALTIPLANO are examples of culture hearths.

Cumulonimbus. Huge, dense CLOUDS that can rise up into the STRATOSPHERE. Cumulonimbus clouds produce LIGHTNING and THUNDERSTORMS, so the base of a cumulonimbus cloud can be dark while the top is gleaming white. The flat or anvil-shaped top of the cloud is sometimes called a thunderhead. See also CLOUDS.

Cumulus. Puffy CLOUDS ranging from small to extremely large. Cumulus clouds occur below 6,500 feet (2,000 meters). These clouds are sometimes compared to cotton balls or cauliflower. Coastal REGIONS see cumulus clouds every DAY.

Curie point. TEMPERATURE at which a magnetic MINERAL locks in its magnetization. Also known as Curie temperature.

Cycle. Sequence of naturally recurring events and processes. Most cycles consume ENERGY to move a substance through the ENVIRONMENT.

Cycle of erosion. Influential MODEL of LANDSCAPE change proposed by William Morris Davis near the end of the nineteenth century. The UPLIFT of a relatively flat surface, or PLAIN, in an area of moderate RAINFALL and TEMPERATURE, led to gradual EROSION of the initial surface in a sequence Davis categorized as Youth, Maturity, and Old Age. The final landscape was called PENEPLAIN. Davis also recognized the stage of REJUVENATION, when a new uplift could give new ENERGY to the cycle, leading to further downcutting and erosion. The model also was used to explain the sequence of LANDFORMS developed in REGIONS of ALPINE GLACIERS. The model has been criticized as misleading, since CRUSTAL MOVEMENT is continuous and more frequent than Davis perhaps envisaged, but it remained useful as a description of TOPOGRAPHY. Also known as the Davisian cycle or geomorphic cycle.

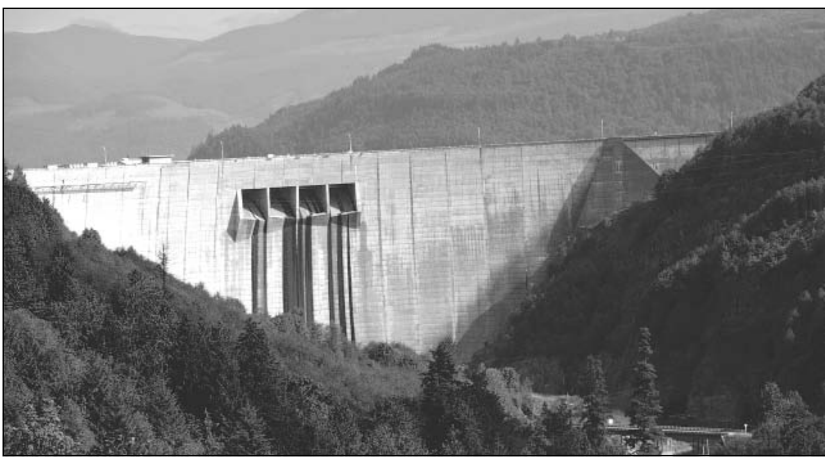
Cyclone. Low-pressure system of rotating WINDS, converging and ascending. In the NORTHERN HEMISPHERE, the rotation is COUNTERCLOCKWISE; in the SOUTHERN HEMISPHERE, the rotation is CLOCKWISE. See also ANTICYCLONE; HURRICANE; TROPICAL CYCLONE; TYPHOON.

Cyclonic rain. In the NORTHERN HEMISPHERE winter, two low-pressure systems or CYCLONES—the Aleutian Low and the Icelandic Low—develop over the OCEAN near 60 DEGREES north LATITUDE. The polar FRONT forms where the cold and relatively dry ARCTIC AIR meets the warmer, moist air carried by westerly WINDS. The warm air is forced upward, cools, and condenses. These cyclonic STORMS often move south, bringing winter PRECIPITATION to North America, especially to the STATES of Washington and Oregon.

Cylindrical projection. MAP PROJECTION that represents the earth's surface as a rectangle. It can be imagined as a cylinder of paper wrapped around a globe with a light source at its center; the images of the CONTINENTS would be projected onto the paper. In reality, MAPS are constructed mathematically. It is impossible to show the North Pole or South Pole on a cylindrical projection. Although the map is conformal, distortion of area is extreme beyond 50 DEGREES north and south LATITUDES. The Mercator projection, developed in the sixteenth century by the Flemish cartographer Gerhardus Mercator, is the best-known cylindrical projection. It has been popular with seamen because the shortest route between two PORTS (the GREAT CIRCLE route) can be plotted as straight lines that show the COMPASS direction that should be followed. Use of this projection for other purposes, however, can lead to misunderstandings about size; for example, compare Greenland on a globe and on a Mercator map. See also MAPS.

Dale. English word for a VALLEY.

Dam. Structure built across a RIVER to control the flow of water. It is thought that the earliest dams were constructed to store water for IRRIGATION during the dry part of the year. Modern dams store water for cities and industry and also produce hydroelectricity. The LAKE that forms artificially behind a dam is called a RESERVOIR. Every dam must have a SPILLWAY so excess water is released when the level in the reservoir becomes too high. As engineering TECHNOLOGY led to the construction of huge dams in the twentieth century, many critics voiced opposition. The waters of the reservoir often inundated areas of great scenic beauty, valuable agricultural land, and historic structures. Large dams also displaced many people.



Dams are structures built across streams to control the flow of water. Lakes that form artificially behind dams are called reservoirs. (PhotoDisc)

Date line. See INTERNATIONAL DATE LINE.

Datum level. Baseline or level from which other heights are measured, above or below. MEAN SEA LEVEL is the datum commonly used in surveying and in the construction of TOPOGRAPHIC MAPS.

Davisian cycle. See CYCLE OF EROSION.

Dawn. Period of time from the first appearance of sunlight in the morning to when the SUN is fully above the HORIZON. The length of time varies with LATITUDE, being shortest at the EQUATOR. At the POLES, dawn lasts for about seven weeks during the summer months.

Day. Interval of time between successive passages of the SUN or star over a MERIDIAN of the earth.

Daylight saving time. System of seasonal adjustments in CLOCK settings designed to increase hours of evening sunlight during summer months.

In the spring, clocks are set ahead one hour; in the fall, they are put back to standard time. In North America, these changes are made on the first Sunday in April and the last Sunday in October. The U.S. Congress standardized daylight saving time in 1966; however, parts of Arizona, Indiana, and Hawaii do not follow the system.

Death rate. Annual number of deaths per one thousand individuals of a given POPULATION. For the United States, the death rate was nine persons (per thousand per year) at the end of the twentieth century. Shortened form of "CRUDE DEATH RATE."

Débâcle. In a scientific context, this French word means the sudden breaking up of ice in a RIVER in the spring, which can lead to serious, sudden flooding.

Debris avalanche. Large mass of SOIL and ROCK that falls and then slides on a cushion of AIR downhill rapidly as a unit.

Debris flow. Flowing mass consisting of water and a high concentration of SEDIMENT with a wide RANGE of size, from fine muds to coarse gravels.

Deciduous forest. Mixed, broadleaf FOREST that was once common in moist, temperate CLIMATES in the United States, Europe, and Asia.

Birch trees can be found in boreal forests throughout the world. (PhotoDisc)

Common trees were oak, ash, elm, walnut, maple, and birch. The leaves of the trees turn red or yellow as the WEATHER becomes cool, and the branches are bare throughout the winter when TEMPERATURES fall below freezing. Centuries of clearing have destroyed significant portions of deciduous forests.

Declination, magnetic. Measure of the difference, in DEGREES, between the earth's NORTH MAGNETIC POle and the North Pole on a MAP; this difference changes slightly each year. The needle of a magnetic COMPASS points to the earth's geomagnetic pole, which is not exactly the same as the North Pole of the geographic GRID or the set of lines of LATITUDE and LONGITUDE. The geomagnetic poles, north and south, mark the ends of the AXIS of the earth's MAGNETIC FIELD, but this field is not stationary. In fact, the geomagnetic poles have completely reversed hundreds of times throughout earth history. Lines of equal magnetic declination are called ISOGONIC LINES.

Declination of the Sun. LATITUDE of the SUBSOLAR POINT, the PLACE on the earth's surface where the SUN is directly overhead. In the course of a year, the declination of the Sun migrates from 23.5 DEGREES north LATITUDE, at the (northern) summer SOLSTICE, to 23.5 degrees south latitude, at the (northern) WINTER SOLSTICE. Hawaii is the only part of the United States that experiences the Sun directly overhead twice a year.

Deep. Relatively deep part of an OCEAN, part of the ABYSSAL PLAIN.

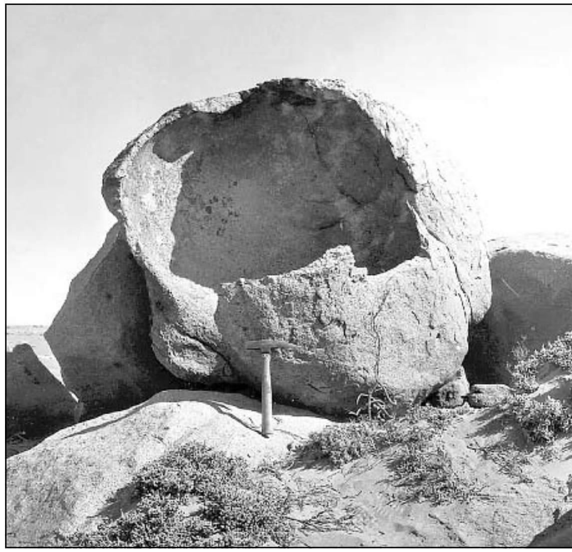
Deep ecology. View or philosophy of nature that has two major aspects. Self-realization is the view that humans are merely one part of a complex world system with many different parts. Egalitarianism, or biospherical egalitarianism, places the whole earth at the center of life and holds that every species has the same rights; humans are not superior to, or more important than, any other species, or even ROCKS. Deep ecologists argue that humans should respect the nonhuman world and not regard it as merely a means to sustain human life.

Deep-focus earthquakes. EARTHQUAKES occurring at depths ranging from 40 to 400 miles (65 to 650 km.) below the earth's surface. This RANGE of depths represents the zone from the base of the earth's CRUST to approximately one-quarter of the distance into Earth's MANTLE. Deep-focus earthquakes provide scientists information about the PLANET's interior structure, its composition, and SEISMICITY. Observation of deep-focus earthquakes has played a fundamental role in the discovery and understanding of PLATE TECTONICS.

Deep-ocean currents. Deep-ocean currents involve significant vertical and horizontal movements of seawater. They distribute oxygen- and nutrient-rich waters throughout the world's OCEANS, thereby enhancing biological productivity.

Deep-sea plain. See ABYSSAL PLAIN.

Defile. Narrow MOUNTAIN PASS or GORGE through which troops could march only in single file.



Example of deflation—a block of granite hollowed out by windblown sand in Chile's Atacama Province. (U.S. Geological Survey)

Deflation. EROSION by WIND, resulting in the removal of fine particles. The LANDFORM that typically results is a deflation hollow.

Deforestation. Removal or destruction of FORESTS. In the late twentieth century, there was widespread concern about tropical deforestation—destruction of the tropical RAIN FOREST—especially that of Brazil. Forest clearing in the TROPICS is uneconomic because of low SOIL fertility.

Clear-cutting of forests for commercial timber is one of the major contributors to deforestation. (PhotoDisc)

Deforestation causes severe EROSION and environmental damage; it also destroys habitat, which leads to the EXTINCTION of both plant and animal species.

Degradation. Process of CRATER EROSION from all processes, including WIND and other meteorological mechanisms. See also DENUDATION.

Degree (geography). Unit of LATITUDE OR LONGITUDE in the geographic GRID, used to determine ABSOLUTE LOCATION. One degree of latitude is about 69 miles (111 km.) on the earth's surface. It is not exactly the same everywhere, because the earth is not a perfect sphere. One degree of longitude varies greatly in length, because the MERIDIANS converge at the POLES. At the EQUATOR, it is 69 miles (111 km.), but at the North or South Pole it is zero.

Degree (temperature). Unit of MEASUREMENT of TEMPERATURE, based on the CELSIUS SCALE, except in the United States, which uses the FAHRENHEIT SCALE. On the Celsius scale, one degree is one-hundredth of the difference between the freezing point of water and the boiling point of water.

Dehydration. Release of water from pore spaces or from hydrous MINERALS as a result of increasing TEMPERATURE.

Delta. Area of DEPOSITION of ALLUVIUM where a RIVER enters the SEA or a LAKE. The Greek letter "delta" was used to describe the MOUTH of the Nile River; not all river deltas have this shape. Some are elongated along DISTRIBUTARIES and are called bird's-foot deltas, for example the Mississippi River. The largest delta in the world is the combined delta of the Ganges and Brahmaputra Rivers in Bangladesh.

The combined delta of the Ganges and Brahmaputra Rivers in Bangladesh is the world's largest. (PhotoDisc)

Demographic measure. Statistical data relating to POPULATION.

Demographic transition. MODEL of POPULATION change that fits the experience of many European countries, showing changes in birth and death rates. In the first stage, in preindustrial countries, population size was stable because both BIRTH RATES and DEATH RATES were high. Agricultural reforms, together with the INDUSTRIAL REVOLUTION and subsequent medical advances, led to a rapid fall in the death rate, so that the second and third stages of the model were periods of rapid population growth, often called the POPULATION EXPLOSION. In the fourth stage of the model, birth rates fall markedly, leading again to stable population size.

Demography. Study of POPULATION, especially of changes measured by such statistics as BIRTH RATES, DEATH RATES, and MIGRATION.

Dendritic drainage. Most common pattern of STREAMS and their TRIBUTARIES, occurring in areas of uniform ROCK type and regular slope. A MAP, or aerial photograph, shows a pattern like the veins on a leaf—smaller streams join the main stream at an acute angle.

Denudation. General word for all LANDFORM processes that lead to a lowering of the LANDSCAPE, including WEATHERING, mass movement, EROSION, and transport.

Dependency. Territory, such as a COLONY OF PROTECTORATE, ruled by a NATION of which it is not an integral part.

Deposition. Laying down of SEDIMENTS that have been transported by water, WIND, or ice.

Depression. Term used in European countries for a midlatitude CYCLONE or low-pressure system. PRECIPITATION usually results as these systems move from west to east across Europe or North America.

Deranged drainage. LANDSCAPE whose integrated drainage network has been destroyed by irregular glacial DEPOSITION, yielding numerous shallow LAKE BASINS.

Derivative maps. MAPS that are prepared or derived by combining information from several other maps.

Desalinization. Process of removing SALT and MINERALS from seawater or from saline water occurring in AQUIFERS beneath the land surface to render it fit for AGRICULTURE or other human use.

Desert. Large REGION of dry CLIMATE, which consequently has a sparse human POPULATION. The desert BIOME occupies about one-quarter of the earth's lands and comprises a distinctive assemblage of FLORA and FAUNA with specific adaptations to this physical ENVIRONMENT. Desert plants are mostly small and sparse and have XEROPHYTIC characteristics. Animals are small and often nocturnal. The hot deserts of the world are located in northern Africa through southwest Asia, and in Australia, the southwest United States, Chile, and southwest Africa. There also are cool or temperate deserts, located in the northern United States and extensively in central Asia, where ELEVATION is part of the reason

The spectacular sand dunes of Asia's Gobi Desert display the constantly changing ridges and shapes caused by wind. (Digital Stock)

for this difference. Desert LANDFORMS are quite distinctive. Although SAND DUNES are popularly associated with deserts, they cover only 10 percent of the world's deserts. Stony, mountainous desert LANDSCAPES are much more common, especially in United States deserts.

Desert climate. Low PRECIPITATION, low HUMIDITY, high daytime TEMPERATURES, and abundant sunlight are characteristics of desert climates. The hot DESERTS of the world generally are located on the western sides of CONTINENTS, at LATITUDES from fifteen to thirty DEGREES north or south of the EQUATOR. One definition, based on precipitation, defines deserts as areas that receive between 0 and 9 inches (0 to 250 millimeters) of precipitation per year. REGIONS receiving more precipitation are considered to have a SEMIDESERT climate, in which some AGRICULTURE is possible.

Desert pavement. Surface covered with smoothed PEBBLES and gravels, found in arid areas where DEFLATION (WIND EROSION) has removed smaller particles. Called a "gibber plain" in Australia and a *reg* in Arabic-speaking countries. See also ERG.

Desertification. Increase in DESERT areas worldwide, largely as a result of overgrazing or poor agricultural practices in semiarid and marginal CLIMATES. DEFORESTATION, DROUGHT, and POPULATION increase also contribute to desertification. The REGION of Africa just south of the Sahara Desert, known as the SAHEL, is the largest and most dramatic demonstration of desertification.

Detrital minerals. See DETRITUS.

Detrital rock. SEDIMENTARY ROCK composed mainly of grains of silicate MINERALS as opposed to grains of calcite or CLAYS.

Detritus. MINERALS which have been eroded, transported, and deposited as SEDIMENTS. Also called detrital minerals.

Development. Level of INDUSTRIALIZATION and standard of living in a COUNTRY. Economic geographers study various measures of development. The countries of the world can be divided into four levels of economic development: high-income, upper-middle-income, lower-middle-income, and low-income. The low-income countries are concentrated in Africa and Asia. In the past, terms such as "undeveloped," "less developed," and "underdeveloped" were used for the various low-income to lower-middle-income economies, as was the now-outdated term THIRD WORLD.

Devolution. Breaking up of a large COUNTRY into smaller independent political units is the final and most extreme form of devolution. The Soviet Union devolved from one single country into fifteen separate countries in 1991. At an intermediate level, devolution refers to the granting of political autonomy or self-government to a REGION, without a complete split. The reopening of the Scottish Parliament in 1999 and the Northern Ireland parliament in 2000 are examples of devolution; the Parliament of the United Kingdom had previously met only in London and made laws there for all parts of the country. Canada experienced devolution with the creation of the new territory of Nunavut, whose residents elect the members of their own legislative assembly.

Dew. Deposit of water droplets on objects whose surface has sufficiently cooled, generally by loss of heat through nighttime RADIATION, to a TEMPERATURE sufficiently low to condense water vapor from the surrounding AIR. See also HOAR FROST.

Dew on a spider web. (PhotoDisc)

Dew point. TEMPERATURE at which an AIR mass becomes saturated and can hold no more moisture. Further cooling leads to CONDENSATION. At ground level, this produces DEW.

Diagenesis. Conversion of unconsolidated SEDIMENT into consolidated ROCK after burial by the processes of compaction, cementation, recrystallization, and replacement.

Dialect. Regional variation of a standard LANGUAGE. It can consist of different pronunciations and different word usage. Speakers of the language can understand the dialect, even if they do not speak it. Within the United States, there are several regional dialects; for example, people in Texas speak a different dialect from people in Boston.

Diaspora. Dispersion of a group of people from one CULTURE to a variety of other REGIONS or to other lands. A Greek word, used originally to refer to the Jewish diaspora. Jewish people now live in many countries, although they have Israel as a HOMELAND. Similar to this are the diasporas of the Irish and the Chinese.

Diastrophism. Deformation of the earth's CRUST by faulting or FOLDING.

Diatom ooze. Deposit of soft mud on the OCEAN floor consisting of the shells of diatoms, which are microscopic single-celled creatures with SILICA-rich shells. Diatom ooze deposits are located in the southern Pacific around Antarctica and in the northern Pacific. Other PELAGIC, or deep-ocean, SEDIMENTS include CLAYS and calcareous ooze.

Differential weathering. Physical and CHEMICAL WEATHERING that occurs at irregular or different rates, caused by variations in composition and resistance of a ROCK or by differences in intensity of WEATHERING, and usually resulting in an uneven surface where more resistant material stands higher or protrudes above less resistant parts.

Differentiation. Layering within ROCK that results from differences in density; the lighter material rises to the surface while the heaviest material sinks to the bottom of a mixture of substances.

Diffusion. Process of growth and spread outward from a center or core area over time. It is applied to many phenomena in CULTURAL GEOGRAPHY, such as the spread of disease, or the growth of a CITY, LANGUAGE, and ideas. Modern telecommunications make possible almost instantaneous diffusion of ideas, images, and sounds throughout the developed world.

Dike (geology). LANDFORM created by IGNEOUS intrusion when MAGMA or molten material within the earth forces its way in a narrow band through overlying ROCK. The dike can be exposed at the surface through EROSION.

Dike (water). Earth wall or DAM built to prevent flooding; an EMBANKMENT or artificial LEVEE. Sometimes specifically associated with structures built in the Netherlands to prevent the entry of seawater. The land behind the dikes was reclaimed for AGRICULTURE; these new fields are called POLDERS.

Dingle. Old English word for a small, secluded VALLEY with trees.

Distance-decay function. Rate at which an activity diminishes with increasing distance. The effect that distance has as a deterrent on human activity is sometimes described as the FRICTION OF DISTANCE. It occurs because of the time and cost of overcoming distances between people and their desired activity. An example of the distance-decay function is the rate of visitors to a football stadium. The farther people have to travel, the less likely they are to make this journey.

Distributary. STREAM that takes waters away from the main CHANNEL of a RIVER. A DELTA usually comprises many distributaries. Also called distributary channel.

Distribution. Way in which some feature, or group of features, under examination is spread out over a REGION. Geographers look for patterns of distribution and seek explanations for the patterns.

Diurnal range. Difference between the highest and lowest TEMPERATURES registered in one twenty-four-hour period.

Diurnal tide. Having only one high tide and one low tide each lunar DAY; TIDES on some parts of the Gulf of Mexico are diurnal.

Divergence. Process of fracturing and dissecting a SUPERCONTINENT, thereby creating new oceanic ROCK; divergence represents the initial half of the supercontinent CYCLE.

Divergent boundary. BOUNDARY that results where two TECTONIC PLATES are moving apart from each other, as is the case along MID-OCEANIC RIDGES.

Divergent margin. Area where the earth's CRUST and LITHOSPHERE form by SEAFLOOR SPREADING.

Divergent plates. TECTONIC PLATE BOUNDARY where two PLATES are moving apart.

Diversity. Variety of life, usually described in terms of the number of species present.

Divide. RIDGE that separates one DRAINAGE BASIN from the adjoining basin. The CONTINENTAL DIVIDES of the United States separate those STREAMS that flow to the Pacific Ocean, the Gulf of Mexico, the Atlantic Ocean, Hudson Bay, and the Arctic Ocean. Also known as drainage divide.

Doctor. WINDS OF BREEZES that bring relief from unpleasant or oppressive WEATHER conditions. In Western Australia, the cool sea breeze that comes in the afternoon is called the Fremantle Doctor. A similar phenomenon in South Africa is called the Cape Doctor. The names come from an earlier time, but these winds have become important in reducing AIR POLLUTION in the cities of Perth and Cape Town, respectively.

Doldrums. Narrow BELT of OCEANS on both sides of the THERMAL EQUATOR (INTERTROPICAL CONVERGENCE ZONE) which is a zone of calms or light variable WINDS. In the days of travel by sailing ship, sailors feared becoming trapped in this part of the world. The epic poem *The Rime of* *the Ancient Mariner* (1857) by Samuel Taylor Coleridge describes the imaginary plight of a vessel caught in the doldrums. Now, the term "in the doldrums" has come to mean a feeling of downheartedness.

Doline. Large SINKHOLE or circular depression formed in LIMESTONE areas through the CHEMICAL WEATHERING process of carbonation.

Dolomite. MINERAL consisting of calcium and magnesium carbonate compounds that often forms from PRECIPITATION from seawater; it is abundant in ancient ROCKS.

Dome. Small circular structure formed by FOLDING or warping of the earth's CRUST, such as are found among the Ozark Mountains and the Black Hills of South Dakota.

Domestication. Change from wild to tame or suitable for human agricultural use. The domestication of animals and plants, which began several thousand years ago, led to the farming of crops and the grazing of animals, making CIVILIZATION possible.

Donga. South African word for a dry STREAMBED in an arid area. See also ARROYO, WADI, and WASH.

Double cropping. In warm moist CLIMATES, farmers can produce two crops from the same field in a single year. This is the case with rice growing in southeast Asian countries and in southern China. Fertile SOILS are an advantage in these REGIONS as well.

Downburst. Downward outflowing of AIR and the associated WIND shear from a THUNDERSTORM that is especially hazardous to aircraft.

Downland. Flat to rolling UPLAND area or PLATEAU, covered with grass and used mainly for grazing sheep. Often known as downs.

Downwelling. Sinking of OCEAN water.

Drainage. Collection and removal of water from PRECIPITATION by STREAM CHANNELS. The geology of an area influences the drainage pattern. Typically, a DENDRITIC pattern forms in an area of uniform slope and rocktype. A CENTRIPETAL drainage pattern indicates a GRABEN. On a DOME or VOLCANO, a radial pattern forms. In areas of alternating hard and soft ROCKS, usually areas of FOLDING, a trellis pattern is seen. See also INTERNAL DRAINAGE.

Drainage basin. Area of the earth's surface that is drained by a STREAM. Drainage basins vary greatly in size, but each is separated from the next by RIDGES, or drainage DIVIDES. The CATCHMENT of the drainage basin is the WATERSHED.

Drainage density. Total length of all STREAMS in a DRAINAGE BASIN divided by the area of that basin. A humid CLIMATE has a high drainage density, while DESERTS have a low drainage density.

Drainage divide. See DIVIDE.

Drift ice. ARCTIC or ANTARCTIC ice floating in the open SEA.

Drizzle. Very fine rain, comprising small raindrops.

Drought. Prolonged period with no PRECIPITATION; abnormally dry WEATHER sufficiently prolonged for the lack of precipitation to cause a serious HYDROLOGICAL imbalance. Drought is a relative rather than an absolute condition, but the end result is a water shortage for an activity such as plant growth or for some group of people such as farmers.

Drowned valley. Feature occurring where a SHORELINE has been submerged, usually through rising SEA LEVEL. Where a series of long HEADlands and alternating ESTUARIES occur, this is called a RIA COAST. The northeastern coast of the United States has many long narrow INLETS that were RIVER VALLEYS when sea level was lower.

Drumlin. Low HILL, shaped like half an egg, formed by DEPOSITION by CONTINENTAL GLACIERS. A drumlin is composed of TILL, or mixed-size materials. The wider end faces upstream of the glacier's movement; the tapered end points in the direction of the ice movement. Drumlins usually occur in groups or swarms.

Dune. Deposits of SAND of various shapes—crescents, RIDGES, and heaps. SAND DUNES are moved by WINDS.

Duricrust. See LATERITE.

Dust. Particles smaller than 62 micrometers in size. Dust particles are moved great distances by WINDS, from one CONTINENT to another. Dust particles may come from SOIL EROSION, as was the case in the famous DUST BOWL of the 1930's.

Dust Bowl. Part of the southwestern Great PLAINS of the United States, in Kansas, Texas, Oklahoma, New Mexico, and Colorado. In the 1920's, GRASSLAND that formerly had been used for cattle grazing was plowed up for grain growing. This fragile ENVIRONMENT then suffered from poor agricultural practices, combined with a long DROUGHT in the 1930's. The TOPSOIL was carried away as DUST by strong WINDS. Daylight was obscured by clouds of dust so thick that streetlights burned throughout the DAY in cities such as Kansas City and St. Louis. During the Great Depression, thousands of people from the Dust Bowl abandoned their farms, many moving to California in hopes of a better life there. The federal government acted to stabilize the REGION in the 1940's.

Dust devil. Whirling cloud of DUST and small debris, formed when a small patch of the earth's surface becomes heated, causing hot AIR to rise;

Dust devils. (PhotoDisc)

cooler air then flows in and begins to spin. The resulting dust devil can grow to heights of 150 feet (50 meters) and reach speeds of 35 miles (60 km.) per hour. See WILLY WILLY.

Dust dome. Dome of AIR POLLUTION, composed of industrial gases and particles, covering every large CITY in the world. The pollution sometimes is carried downwind to outlying areas.

Dust storm. Particles such as DUST transported long distances by WINDS. The size of the particles influences the distance traveled. STORMS from the Sahara Desert can carry dust even north of the Alps in Europe. Removal of particles by the wind is called DEFLATION.

Early Paleozoic. That part of geologic history that is somewhat younger than about 550 million years before the present.

Earth pillar. Formation produced when a boulder or caprock prevents EROSION of the material directly beneath it, usually CLAY. The clay is easily eroded away by water during RAINFALL, except where the overlying ROCK protects it. The result is a tall, slender column, as high as 20 feet (6.5 meters) in exceptional cases.

Earth radiation. Portion of the electromagnetic spectrum, from about 4 to 80 microns, in which the earth emits about 99 percent of its RADIATION.

Earth tide. Slight deformation of Earth resulting from the same forces that cause OCEAN TIDES, those that are exerted by the MOON and the SUN.

Earthflow. Term applied to both the process and the LANDFORM characterized by fluid downslope movement of SOIL and ROCK over a discrete plane of failure; the landform has a HUMMOCKY surface and usually terminates in discrete lobes.

Earthquake. Movement of the earth's CRUST when there is a sudden release of built-up ENERGY along a FAULT. WAVES travel through the crust, as well as through the underlying MANTLE. Earthquake intensity is measured using the moment magnitude scale. Before 1993, the RICHTER SCALE was commonly used. An early descriptive scale of earthquake intensity is the MERcalli SCALE.

Earthquake focus. Area below the surface of the earth where active movement occurs to produce an EARTHQUAKE.

Earthquake swarm. Number of EARTHQUAKES that occur close together and closely spaced in time.

Earthquake waves. Vibrations that emanate from an EARTHQUAKE; earthquake waves can be measured with a SEISMOGRAPH.

Earth's core. See CORE.

Earth's heat budget. Balance between the incoming SOLAR RADIATION and the outgoing terrestrial reradiation.

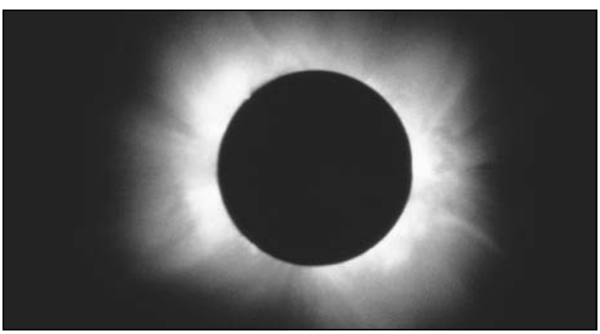
Eastern Hemisphere. The half of the earth containing Europe, Asia, and Africa; generally understood to fall between LONGITUDES 20 DEGREES west and 160 degrees east.

Ebb tide. Outgoing or falling TIDE that, in most parts of the world, occurs twice in a 24-hour period. See also FLOOD TIDE.

Eclipse. Event where all or part of the light emitted, or reflected, by an astronomical object is obscured by another astronomical object.

Eclipse, lunar. Obscuring of all or part of the light of the MOON by the shadow of the earth. A lunar eclipse occurs at the full moon up to three times a year. The surface of the Moon changes from gray to a reddish color, then back to gray. The sequence may last several hours.

Eclipse, solar. At least twice a year, the SUN, MOON, and Earth are aligned in one straight line. At that time, the Moon obscures all the light of the Sun along a narrow band of the earth's surface, causing a total eclipse; in REGIONS of Earth adjoining that area, there is a partial eclipse. A corona (halo of light) can be seen around the Sun at the total eclipse. Viewing a solar eclipse with naked eyes is extremely dangerous and can cause blindness.



Solar eclipse observed from North Dakota on February 26, 1979. (PhotoDisc)

Ecliptic. Intersection of the plane of the earth's ORBIT with the celestial sphere; with the exception of Pluto, the orbital planes of the other PLANETS lie within 7 DEGREES of the ecliptic.

Ecliptic, plane of. Imaginary plane that would touch all points in the earth's ORBIT as it moves around the SUN. The angle between the plane of the ecliptic and the earth's AXIS is 66.5 DEGREES.

Ecological imperialism. Introduction of foreign and exotic species of plants and animals into ECOSYSTEMS. The interchange between the Old World and the New World was often deliberate and beneficial (see COLUMBIAN EXCHANGE), but there were also unintentional introductions. These often had severely detrimental effects on native species and led to problems with feral animals and similar pests like starlings and pigeons, or to noxious weeds such as thistles and dandelions.

Ecology. Science that studies the relationship between living organisms (plants and animals) and their ENVIRONMENT. Ecologists also study individual ECOSYSTEMS in detail.

Economy. System of production, DISTRIBUTION, and consumption of goods and services, usually within a single COUNTRY. Measures of the strength of a country's economy include the GROSS DOMESTIC PRODUCT per capita or the gross national product per capita. The growth of transnational enterprises and international TRADE has led to a global economy.

Ecosystem. Association of living and nonliving parts of a group of plants and animals and their physical ENVIRONMENT.

Edaphic. Related to the SOIL. Edaphic factors that influence plants include HUMUS content, which is related to fertility; soil TEXTURE; soil structure; and the presence of various soil organisms such as bacteria and earthworms.

Eddy. Mass of water that is spun off an OCEAN CURRENT by the current's meandering motion.

Edge cities. Forms of suburban downtown in which there are nodal concentrations of office space and shopping facilities. Edge cities are located close to major freeways or highway intersections, on the outer edges of METROPOLITAN AREAS.

Effective temperature. TEMPERATURE of a PLANET based solely on the amount of SOLAR RADIATION that the planet's surface receives; the effective temperature of a planet does not include the GREENHOUSE temperature enhancement effect.

Ejecta. Material ejected from the CRATER made by a meteoric impact.

Ekman layer. REGION of the SEA, from the surface to about 100 meters down, in which the WIND directly affects water movement.

Ekman spiral. Water movement in lower depths of an ocean that occurs at a slower rate and in a different direction from SURFACE WATER movement.

El Niño. Conditions—also known as El Niño-Southern Oscillation (ENSO) events—that occur every two to ten years and affect WEATHER and OCEAN TEMPERATURES, particularly off the COAST of Ecuador and Peru. Most of the time, the Peru, or Humboldt, Current causes cold, nutrient-rich water to well up off the coast of Ecuador and Peru. During ENSO years, the cold UPWELLING is replaced by warmer SURFACE WATER that does not support PLANKTON and fish. Fisheries decline and seabirds starve. Climatic changes of El Niño can bring FLOODS to normally dry areas and DROUGHT to wet areas. Effects can extend across North and South America, and to the western Pacific Ocean. During the 1990's, the ENSO event fluctuated but did not vanish completely, which caused tremendous damage to fisheries and AGRICULTURE, STORMS and droughts in North America, and numerous HURRICANES.

Elevation. Vertical distance of a point on the earth's surface above or below MEAN SEA LEVEL.

Ellipse. Shape of Earth's ORBIT; rather than a circle with one center, the ellipse has two foci with the SUN located at one of the foci.

Eluviation. Removal of materials from the upper layers of a SOIL by water. Fine material may be removed by SUSPENSION in the water; other material is removed by SOLUTION. The removal by solution is called LEACHING. Eluviation from an upper layer leads to illuviation in a lower layer.

Embankment. Artificial earthen mound built to support a road or to control the movement of water.

Emigration. Leaving one's COUNTRY of birth to settle permanently in another country. See also IMMIGRATION.

Emirate. Islamic NATION ruled by a monarch whose title is emir.

Enclave. Piece of territory completely surrounded by another COUNTRY. Two examples are Lesotho, which is surrounded by the Republic of South Africa, and the Nagorno-Karabakh REGION, populated by Armenians but surrounded by Azerbaijan. The term is also used for smaller regions, such as ethnic neighborhoods within larger cities. See also EXCLAVE.

Endemic. Found in a particular PLACE and no other.

Endemic species. Species confined to a restricted area in a restricted ENVIRONMENT.

Endogenic sediment. SEDIMENT produced within the water column of the body in which it is deposited; for example, calcite precipitated in a LAKE in summer.

Energy. Scientifically, the capacity to do work. Geographers study sources of energy such as FOSSIL FUELS, which are a NONRENEWABLE RESOURCE; ALTERNATIVE (RENEWABLE) ENERGY forms, such as SOLAR energy, HYDROELECTRIC POWER, TIDAL ENERGY, WIND power, and GEOTHERMAL energy; and NUCLEAR ENERGY, which is an abundant RESOURCE but presents serious problems with the disposal of radioactive waste.

ENSO. Acronym for EL NIÑO-Southern Oscillation, used to denote the complete linked atmospheric/OCEAN phenomenon.

Environment. Surroundings of an organism, or a group of organisms, which enable it to survive. Several physical factors are involved in the creation of a suitable natural environment, including TEMPERATURE, moisture, food supply, and waste removal or recycling. The natural environment is sometimes modified extensively by humans, through cooling and heating of buildings, for example. Humans are also concerned with the social environment and the cultural environment.

Environmental degradation. Situation that occurs in slum areas and SQUATTER SETTLEMENTS because of poverty and inadequate INFRASTRUCTURE. Too-rapid human POPULATION growth can lead to the accumulation of human waste and garbage, the POLLUTION of GROUNDWATER, and DENUDATION of nearby FORESTS. As a result, LIFE EXPECTANCY in such degraded areas is lower than in the RURAL communities from which many of the settlers came. INFANT MORTALITY is particularly high. When people leave an area because of such environmental degradation, that is referred to as ecomigration.

Environmental determinism. Theory that the major influence on human behavior is the physical ENVIRONMENT. Some evidence suggests that

TEMPERATURE, PRECIPITATION, sunlight, and TOPOGRAPHY influence human activities. Originally espoused by early German geographers, this theory has led to some extreme stances, however, by authors who have sought to explain the dominance of Europeans as a result of a cool temperate CLIMATE.

Environmental ethics. Philosophy or view of nature that believes humans should always apply moral principles to their treatment of nature and natural phenomena. In other words, the moral values and judgments that are applied to relations between humans should enable people to decide what is right and good with respect to nature. In its extreme form, environmental ethics could hold that ROCKS are of equal value to humans, or that insects such as mosquitoes should have the same rights as humans to a safe and happy life. See also DEEP ECOLOGY.

Environmental justice. Belief that it is unfair to locate many factories, dumps, and hazardous waste facilities in low-socioeconomic areas of cities, or on a global scale, in countries with low-income economies. Advocates of environmental justice emphasize that economic inequality is inevitable in capitalist society, but that it is immoral and even illegal to pollute neighborhoods on the basis of low economic status.

Eocene epoch. Part of the CENOZOIC ERA, dating to about 37 million years ago.

Eolian (aeolian). Relating to, or caused by, WIND. In Greek mythology, Aeolus was the ruler of the winds. EROSION, TRANSPORT, and DEPOSITION are common eolian processes that produce LANDFORMS in DESERT REGIONS.

Eolian deposits. Material transported by the WIND and later deposited.

Eolian erosion. Mechanism of EROSION or CRATER degradation caused by WIND.

Eon. Largest subdivision of geologic time; the two main eons are the PRECAMBRIAN (c. 4.6 billion years ago to 544 million years ago) and the PHANEROZOIC (c. 544 million years ago to the present).

Epeiric sea. Shallow SEA that temporarily (in geologic terms) covers a portion of a CRATON; also termed an EPICONTINENTAL SEA.

Ephemeral stream. Watercourse that has water for only a DAY or so.

Epicenter. Spot on the earth's surface directly above the focus of an EARTHQUAKE. Shock waves produced by the earthquake radiate outward from the focus, allowing SEISMOLOGISTS to locate the epicenter quickly. The RICHTER SCALE, which was used to calculate earthquake magnitude until the 1990's, measured the amplitude of SEISMIC WAVES recorded at least 60 miles (100 km.) from the epicenter. Sometimes a previously unknown FAULT is revealed, a blind fault that does not appear as a surface break. The Northridge earthquake in California in 1994 revealed the LOCATION of a blind THRUST FAULT, where movement had occurred along the FAULT LINE directly beneath the epicenter at Northridge.

Epicontinental sea. Shallow SEAS that are located on the CONTINENTAL SHELF, such as the North Sea or Hudson Bay. Also called an EPEIRIC SEA.

Epifauna. Organisms that live on the seafloor.

Epilimnion. Warmer surface layer of water that occurs in a LAKE during summer stratification; during spring, warmer water rises from great depths, and it heats up through the summer SEASON.

Epoch. Unit of geologic time; a subdivision of a PERIOD.

Equal-area projection. MAP PROJECTION that maintains the correct area of surfaces on a MAP, although shape distortion occurs. The property of such a map is called equivalence. See also MAPS.

Equator. Imaginary line of LATITUDE around the earth's circumference at its widest part, lying equidistant from the POLES and perpendicular to the earth's axis. The equator is a GREAT CIRCLE that divides the earth into two equal halves, the NORTHERN and SOUTHERN HEMISPHERES.

Equinox. Period of equal DAY and night, twelve hours of each, everywhere on Earth, occurring when the CIRCLE OF ILLUMINATION passes through both the POLES. The VERNAL (spring) equinox falls on March 21 and the autumnal (fall) equinox on September 22 in the NORTHERN HEMISPHERE; the SEASONS are reversed in the SOUTHERN HEMISPHERE.

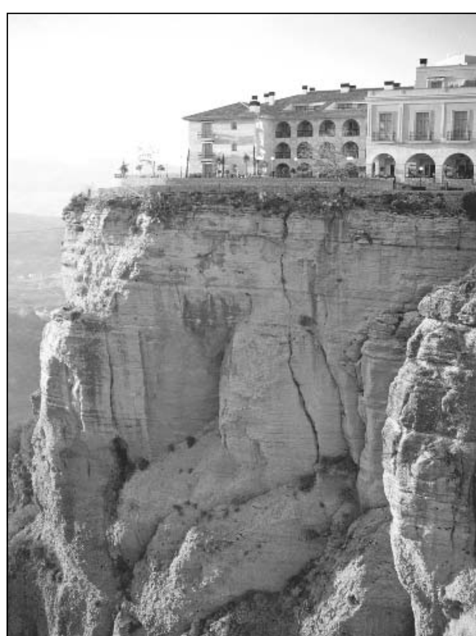
Era. One of the major divisions of geologic time, including one or more PERIODS.

Erg. Sandy DESERT, sometimes called a SEA of SAND. Erg deserts account for less than 30 percent of the world's deserts. "Erg" is an Arabic word.

Erosion. Wearing down and carrying away of earth surface materials by water, WIND, ice, or WAVES. See also CYCLE OF EROSION.

Erratic. See GLACIAL ERRATIC.

Eruption, volcanic. Emergence of MAGMA (molten material) at the earth's surface as LAVA. There are various types of volcanic eruptions, depending on the chemistry of the magma and its viscosity. Scientists refer to effusive and explosive eruptions. Low-viscosity magma generally produces effusive eruptions, where the lava emerges gently, as in Hawaii and Iceland, although explosive events can occur at those SITES as well. Gently sloping



The spectacular cliffs of Parador, Spain, are the product of eons of erosion. (PhotoDisc) shield volcanoes are formed by effusive eruptions; floods, such as the Columbian Plateau, can also result. Explosive eruptions are generally associated with subduction. Much gas, including steam, is associated with magma formed from oceanic crust, and the compressed gas helps propel the explosion. Composite cones, such as Mount Saint Helens, are created by explosive eruptions.

Escarpment. Steep slope, often almost vertical, formed by faulting. Sometimes called a fault scarp.

Esker. Deposit of coarse gravels that has a sinuous, winding shape. An esker is formed by a stream of meltwater that flowed through a tunnel it formed under a continental glacier. Now that the continental glaciers have melted, eskers can be found exposed at the surface in many places in North America.

Estuarine zone. Area near the coastline that consists of estuaries and coastal saltwater wetlands.

Estuary. Place where the mouth of a river enters the sea, causing fresh water and salt water to mix. Tidal ebb and flow occur in an estuary. Estuaries are wetlands that are productive ecosystems.

Etesian winds. Winds that blow from the north over the Mediterranean during July and August.

Ethnic group. Group of people with a distinctive culture, usually including religion, language, traditions, and customs, and sometimes racial ancestry.

Ethnic religion. Religion associated with a particular ethnic group that does not actively seek to convert others to the same religious beliefs. Judaism and Hinduism are good examples of ethnic religions. Religions that actively seek converts are called proselytic religions; Christianity and Islam are examples.

Ethnocentrism. Belief that one's own ethnic group and its culture are superior to any other group.

Ethnography. Study of different cultures and human societies.

Eustacy. Any change in global sea level resulting from a change in the absolute volume of available sea water. Also known as eustatic sea-level change.

Eustatic movement. Changes in sea level.

Evaporation. Change from liquid water to water vapor as water molecules enter the atmosphere. The process is the opposite of condensation.

Evapotranspiration. Combined word for evaporation and transpiration. Both processes transfer moisture from the earth's surface to the atmosphere in the form of water vapor: evaporation from water in the oceans and other water bodies; transpiration from vegetation.

Exclave. Territory that is part of one country but separated from the main part of that country by another country. Alaska is an exclave of the United States; Kaliningrad is an exclave of Russia. See also Enclave.

Yosemite National Park's Half Dome is perhaps the world's most famous example of an exfoliation dome. (PhotoDisc)

Exfoliation. When GRANITE rocks cooled and solidified, removal of the overlying rock that was present reduced the pressure on the granite mass, allowing it to expand and causing sheets or layers of rock to break off. An exfoliation DOME, such as Half Dome in Yosemite National Park, is the resultant LANDFORM.

Exosphere. REGION beyond the earth's ATMOSPHERE, 300 miles (500 km.) above the earth's surface. Only a few atoms of hydrogen and helium are thought to exist in the exosphere.

Exotic stream. RIVER that has its source in an area of high RAINFALL and then flows through an arid REGION or DESERT. The Nile River is the most famous exotic STREAM. In the United States, the Colorado River is a good example of an exotic stream.

Expansion-contraction cycles. Processes of wetting-drying, heating-cooling, or freezing-thawing, which affect SOIL particles differently according to their size.

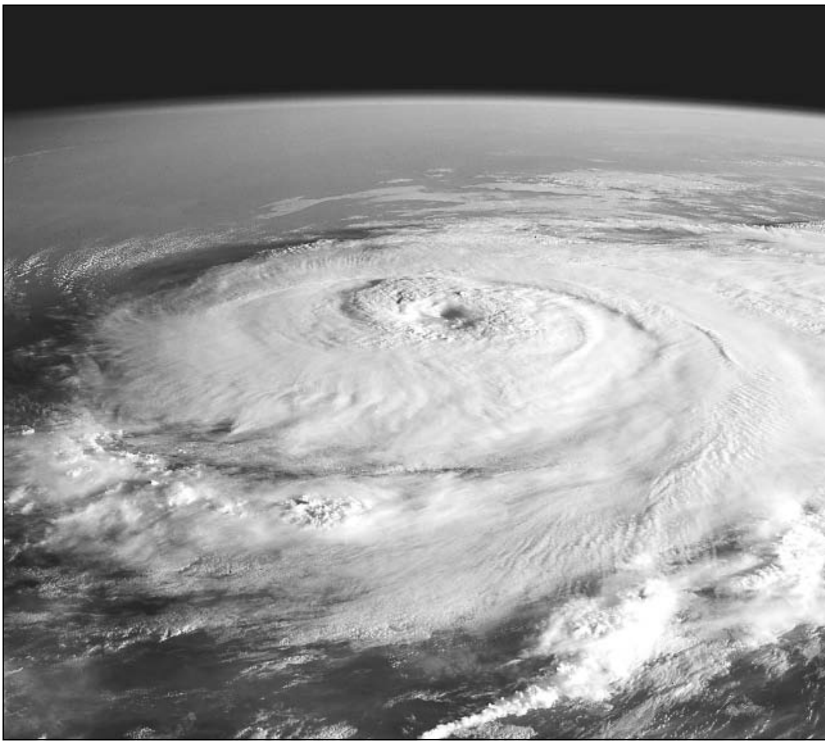
Expansive soils. Expansive soils, SOILS that expand and contract with the gain and loss of water, cause billions of dollars in damage to houses, other lightweight structures, and pavements, exceeding the costs incurred by EARTHQUAKES and flooding.

External economies. Cost savings that firms can enjoy by choosing a LOCATION close to functionally related or similar activities. For example, a soft-drink plant would be better off to locate close to a glass-making factory that would supply bottles with a low cost of transport.

Extinction. Disappearance of a species or large group of animals or plants.

Extrusive rock. Fine-grained, or glassy, ROCK which was formed from a MAGMA that cooled on the surface of the earth.

Eye. Calm central REGION of a HURRICANE, composed of a tunnel with strong sides.



The eye of Hurricane Elena can be easily seen in this September, 1985, photography taken from the space shuttle Discovery. (Corbis)

Fahrenheit scale. TEMPERATURE scale with the freezing point of water at 32 DEGREES (0 degrees Celsius) and its boiling point at 212 degrees (100 degrees Celsius). In the year 2000, the United States was the only major COUNTRY using the Fahrenheit scale instead of the CELSIUS SCALE.

Fall line. Edge of an area of uplifted land, marked by WATERFALLS where STREAMS flow over the edge.

Famine. Severe shortage of food, often caused by DROUGHT.

Fata morgana. Large mirage. Originally, the name given to a multiple mirage phenomenon often observed over the Straits of Messina and supposed to be the work of the fairy ("fata") Morgana. Another famous fata morgana may be seen in Antarctica.

Fathom. MEASUREMENT of water depth used by mariners. A fathom is 6 feet (1.83 meters).

Fathometer. Instrument that uses sound waves or sonar to determine the depth of water or the depth of an object below the water.

Fault. Fracture of the earth's CRUST, usually as a result of an EARTHQUAKE.

Fault-block mountain. See BLOCK MOUNTAIN.

Fault drag. Bending of ROCKS adjacent to a FAULT.

Fault line. Line of breakage on the earth's surface. FAULTS may be quite short, but many are extremely long, even hundreds of miles. The origin of the faulting may lie at a considerable depth below the surface. Movement along the fault line generates EARTHQUAKES.

Fault line in a plowed field.

Fault plane. Angle of a FAULT. When fault blocks move on either side of a fault or fracture, the movement can be vertical, steeply inclined, or sometimes horizontal. In a NORMAL FAULT, the fault plane is steep to almost vertical. In a REVERSE FAULT, one block rides over the other, forming an overhanging FAULT SCARP. The angle of inclination of the fault plane from the horizontal is called the dip. The inclination of a fault plane is generally constant throughout the length of the fault, but there can be local variations in slope. In a STRIKE-SLIP FAULT the movement is horizontal, so no fault scarp is produced, although the FAULT LINE may be seen on the surface.

Fault scarp near Red Canyon Creek, Montana. (U.S. Geological Survey)

Fault scarp. FAULTS are produced through breaking or fracture of the surface ROCKS of the earth's CRUST as a result of stresses arising from tectonic movement. A NORMAL FAULT, one in which the earth movement is predominantly vertical, produces a steep fault scarp. A STRIKE-SLIP FAULT does not produce a fault scarp.

Fauna. Total animal POPULATION of a COUNTRY or REGION, from the largest creatures to the smallest. From the Latin word for "animals." See also FLORA.

Feldspar. Family name for a group of common MINERALS found in such ROCKS as GRANITE and composed of silicates of aluminum together with potassium, sodium, and calcium. Feldspars are the most abundant group of minerals within the earth's CRUST. There are many varieties of feldspar, distinguished by variations in chemistry and crystal structure. Although feldspars have some economic uses, their principal importance lies in their role as rock-forming minerals.

Fell. English word for an open grassy highland, such as a moor.

Felsic rocks. IGNEOUS ROCKS rich in potassium, sodium, aluminum, and SILICA, including GRANITES and related rocks.

Fen. Low-lying WETLAND; a BOG or MARSH.

Feng shui. Ancient Chinese philosophic system that ascribes good and bad qualities to the physical ENVIRONMENT and seeks to determine which LOCATIONS to choose, which to avoid, or how they might be modified to create a favorable set of conditions for human occupancy.

Fertility rate. DEMOGRAPHIC MEASURE of the average number of children per adult female in any given POPULATION. Religious beliefs, education, and other cultural considerations influence fertility rates. See also BIRTH RATE.

Fertilizer. Substance added to the SOIL to improve agricultural production. Plants need nitrogen for their growth, and this can be provided by organic fertilizers such as manure and compost. In high-income economies that practice commercial AGRICULTURE, farmers often use synthetic or manufactured inorganic fertilizers, which are produced in chemical plants and factories. Overapplication of inorganic fertilizer to cropland results in RUNOFF that produces excess nitrogen in STREAMS, LAKES, and, eventually, OCEANS.

Fetch. Distance along a large water surface over which a WIND of almost uniform direction and speed blows.

Feudalism. Social and economic system that prevailed in Europe before the INDUSTRIAL REVOLUTION. The land was owned and controlled by a minority comprising noblemen or lords; all other people were peasants or serfs, who worked as agricultural laborers on the lords' land. The peasants were not free to leave, or to do anything without their lord's permission. Other REGIONS such as China and Japan also had a feudal system in the past.

Fiord. See FJORD.

Firn. Intermediate stage between SNOW and glacial ice. Firn has a granular TEXTURE, due to compaction. Also called NÉVÉ.

Firth. Scottish word for a narrow ESTUARY. The Firth of Forth near Edinburgh is spanned by a famous steel railway BRIDGE constructed in 1890, which has been called Scotland's Eiffel Tower because of its engineering.

Fission, nuclear. Splitting of an atomic nucleus into two lighter nuclei, resulting in the release of neutrons and some of the binding ENERGY that held the nucleus together.

Fissure. Fracture or crack in ROCK along which there is a distinct separation.

Fjord. VALLEY produced at the COAST by a GLACIER that flowed to the SEA. The rising SEA LEVEL FLOODS the glacial TROUGH, producing a fjord.

Kenai Fjords National Park was established on Alaska's Kenai Peninsula—due south of Anchorage—in 1980 to protect the peninsula's many scenic fjords. (PhotoDisc)

The deep water enables ships to sail into fjords, and tourists enjoy the spectacular scenery. Fjord coasts include those of Norway, Alaska, the west coast of the South Island of New Zealand, and less-visited Chile and Antarctica. Also spelled "fiord."

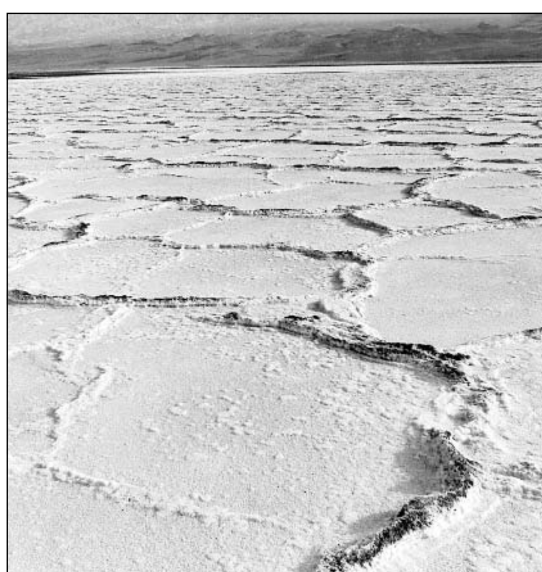
Flash flood. Sudden rush of water down a STREAM CHANNEL, usually in the DESERT after a short but intense STORM. Other causes, such as a DAM failure, could lead to a flash flood.

Flood. Water overflowing a LEVEE and running out over the FLOODPLAIN when the volume of water in a STREAM becomes greater than the stream CHANNEL can contain.

Flood control. Attempts by humans to prevent flooding of STREAMS. Humans have consistently settled on FLOODPLAINS and DELTAS because of the fertile SOIL for AGRICULTURE, and attempts at flood control date back thousands of years. In strictly agricultural societies such as ancient Egypt, people built VILLAGES above the FLOOD levels, but transport and industry made riverside LOCATIONS desirable and engineers devised technological means to try to prevent flood damage. Artificial LEVEES, RESERVOIRS, and DAMS of ever-increasing size were built on RIVERS, as well as bypass CHANNELS leading to artificial floodplains. In many modern dam construction projects, the production of HYDROELECTRIC POWER was more important than flood control. Despite modern TECHNOLOGY, floods cause the largest loss of human life of all natural disasters, especially in low-income countries such as Bangladesh.

Flood tide. Rising or incoming tide. Most parts of the world experience two flood TIDES in each 24-hour period. See also EBB TIDE.

Floodplain. Flat, low-lying land on either side of a STREAM, created by the DEPOSITION of ALLUVIUM from floods. Also called ALLUVIAL PLAIN.



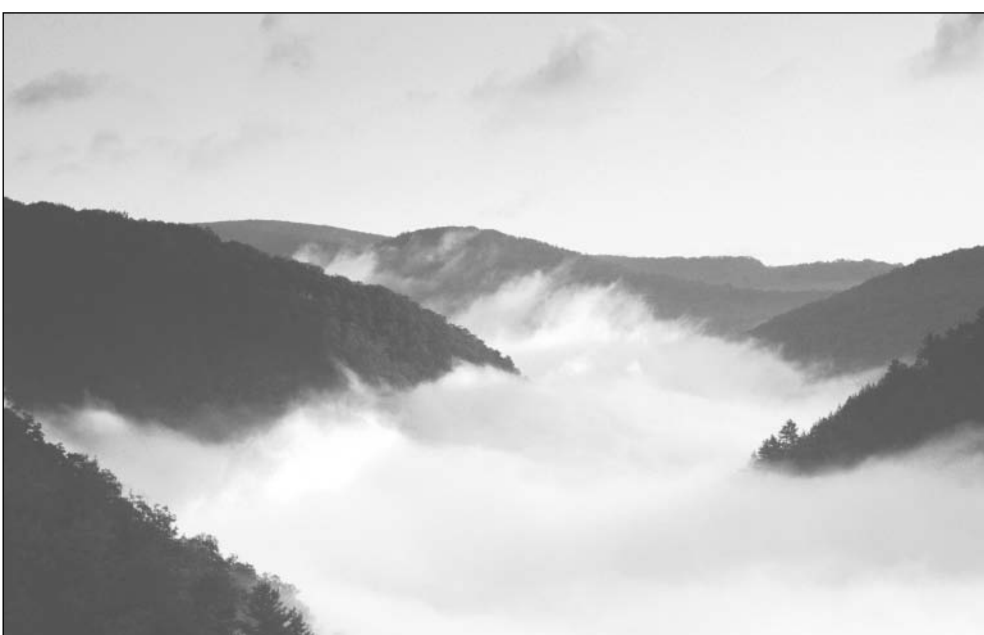
Salt crust that has accumulated on a Southern California playa or lake bed as the result of evaporation. (U.S. Geological Survey)

Flora. All the plants of a COUNTRY or REGION, from the largest trees to the smallest mosses. From the Latin word for "flower." See also FAUNA.

Fluvial. Pertaining to running water; for example, fluvial processes are those in which running water is the dominant agent.

Mexican Hat, a gooseneck bend in the San Juan River in Utah's Goosenecks State Park is a spectacular example of fluvial erosion. (Corbis)

Fog. CLOUD in contact with the ground. Fog is generally a stratiform or layer cloud. Visibility is reduced to less than a half mile, making traveling hazardous.



Fog. (PhotoDisc)

Fog deserts. Coastal DESERTS where FOG is an important source of moisture for plants, animals, and humans. The fog forms because of a cold OCEAN CURRENT close to the SHORE. The Namib Desert of southwestern Africa, the west COAST of California, and the Atacama Desert of Peru are coastal deserts.

Föhn wind. WIND warmed and dried by descent, usually on the LEE side of a MOUNTAIN. In North America, these winds are called the CHINOOK.

Fold mountains. ROCKS in the earth's CRUST can be bent by compression, producing folds. The Swiss Alps are an example of complex FOLDING, accompanied by faulting. Simple upward folds are ANTICLINES, downward folds are SYNCLINES; but subsequent EROSION can produce LANDSCAPES with synclinal MOUNTAINS.

Folding. Bending of ROCKS in the earth's CRUST, caused by compression. The rocks are deformed, sometimes pushed up to form mountain RANGES. See also ISOCLINAL FOLDING.

Foliation. TEXTURE or structure in which MINERAL grains are arranged in parallel planes.

Food chain. Pattern found in nature by which organisms at one level provide food for those at the next level. The food chain represents the flow of ENERGY. At the bottom of the food chain are the producers—plants; all other levels are consumers. At the top of many food chains is the top CARNIVORE. An example of a simple food chain is: wolf eats rabbit, rabbit eats grass.

Food web. Complex network of FOOD CHAINS. Food chains are interconnected, because many organisms feed on a variety of others, and in turn may be eaten by any of a number of predators.

Forced migration. MIGRATION that occurs when people are moved against their will. The Atlantic slave trade is an example of forced migration. People were shipped from Africa to countries in Europe, Asia, and the New World as forced immigrants. Within the United States, some NATIVE AMERICANS were forced by the federal government to migrate to new reservations.

Ford. Short shallow section of a RIVER, where a person can cross easily, usually by walking or riding a horse. To cross a STREAM in such a manner.

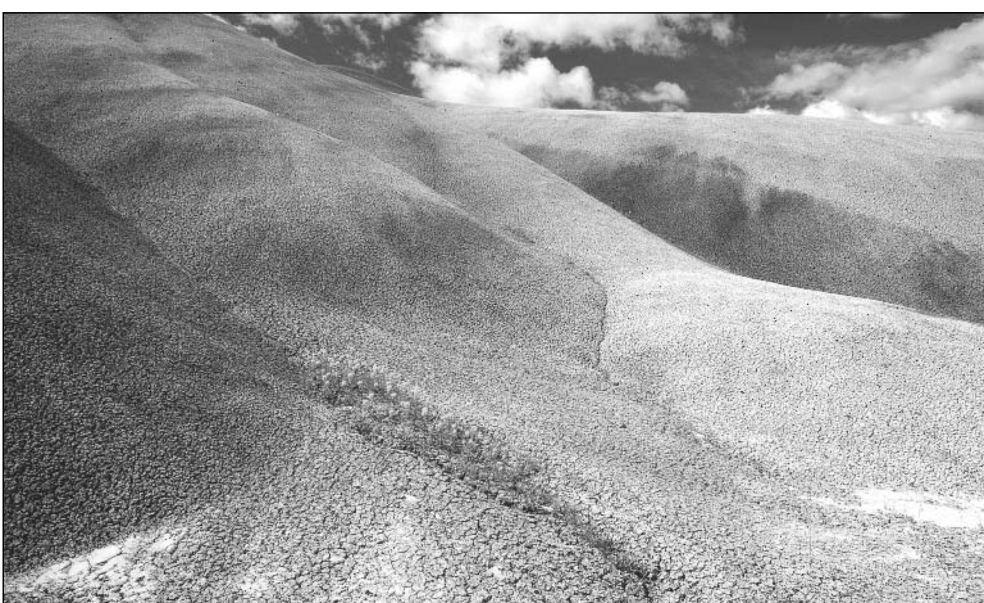
Forest. Trees growing so closely together that their canopies meet or overlap. The existence of forest means abundant PRECIPITATION. In the TROPICS, tropical RAIN FOREST is found; in cooler midlatitude areas, DECIDUOUS FORESTS grow; in the cold northern REGIONS, BOREAL (CONIFEROUS) forests are evident. Where there is insufficient precipitation, WOODLAND or scrub is the dominant VEGETATION type. For centuries, forests have been removed for construction timbers, firewood, or farmland. Such DEFORESTATION can cause regional mudslides and FLOODS and, on a global scale, GLOBAL WARMING.

Formal region. Cultural REGION in which one trait, or group of traits, is uniform. LANGUAGE might be the basis of delineation of a formal cul-

Mormon temple in Salt Lake City, Utah, the center of world Mormonism and an example of a formal region. (Corbis)

tural region. For example, the Francophone region of Canada constitutes a formal region based on one single trait. One might also identify a formal Mormon region centered on the STATE of Utah, combining RELIGION and LANDSCAPE as defining traits. Cultural geographers generally identify formal regions using a combination of traits.

Fossil. Remains of ancient plants or animals preserved in layers of SEDIMENTARY ROCK. Most fossils belong to species that are now extinct.



Fossil beds. (PhotoDisc)

The study of fossils led to the development of the geologic time SCALE and the realization that the earth was billions of years old. Fossils now are dated by scientific methods such as CARBON DATING.

Fossil fuel. Deposit rich in hydrocarbons, formed from organic materials compressed in ROCK layers—COAL, OIL, and NATURAL GAS.

Fossil record. Fossil record provides evidence that addresses fundamental questions about the origin and history of life on the earth: When life evolved; how new groups of organisms originated; how major groups of organisms are related. This record is neither complete nor without biases, but as scientists' understanding of the limits and potential of the fossil record grows, the interpretations drawn from it are strengthened.

Fossilization. Processes by which the remains of an organism become preserved in the ROCK record.

Foucault's pendulum. Nineteenth century French physicist Jean-Bernard-Léon Foucault used a giant pendulum to demonstrate the ROTATION of the earth on its AXIS. While the pendulum swings to and fro in one plane, the earth rotates beneath it so the relative position changes. In the NORTHERN HEMISPHERE, a pendulum rotates CLOCKWISE because of the CORIOLIS EFFECT. Foucault also invented the gyroscope.

Fracture zones. Large, linear zones of the seafloor characterized by steep CLIFFS, irregular TOPOGRAPHY, and FAULTS; such zones commonly cross and displace oceanic RIDGES by faulting.

Free association. Relationship between sovereign NATIONS in which one nation—invariably the larger—has responsibility for the other nation's defense. The Cook Islands in the South Pacific have such a relationship with New Zealand.

Fresh water. Water with less than 0.2 percent dissolved SALTS, such as is found in most STREAMS, RIVERS, and LAKES.

Friction of distance. Distance is of prime importance in social, political, economic, and other relationships. Large distance has a negative effect on human activity. The time and cost of overcoming distance can be a deterrent to various activities. This has been called the friction of distance.

Frigid zone. Coldest of the three CLIMATE zones proposed by the ancient Greeks on the basis of their theories about the earth. There were two frigid zones, one around each POLE. The Greeks believed that human life was possible only in the TEMPERATE ZONE.

Fringing reef. Type of CORAL REEF formed at the SHORELINE, extending out from the land in shallow water. The top of the coral may be exposed at low TIDE.

Front. BOUNDARY between two AIR masses with different TEMPERATURE and moisture characteristics. When warm air moves in, a warm front is produced; when cold air moves in, a COLD FRONT is produced. Rain and changes in temperature and WIND direction accompany the passage of a front. A typical midlatitude CYCLONE, as it moves across North America from west to east, comprises a warm front followed by a cold front. Fronts can be stationary, when no movement is taking place, or occluded, when a cold front overtakes a warm front.

Frontier. Remote, sparsely populated REGION, which may hold potential for DEVELOPMENT, such as MINERAL deposits. Alaska might be regarded as the "last frontier" of the United States.

Frontier Thesis. Thesis first advanced by the American historian Frederick Jackson Turner, who declared that American history and the American character were shaped by the existence of empty, FRONTIER lands that led to exploration and westward expansion and DEVELOPMENT. The closing of the frontier occurred when transcontinental railroads linked the East and West Coasts and SETTLEMENTS spread across the United States. This thesis was used by later historians to explain the history of South Africa, Canada, and Australia. Critics of the Frontier Thesis point out that minorities and women were excluded from this view of history.

Frost. Thin white covering of ice crystals formed on the surface of objects and plants by the freezing of water vapor when the TEMPERATURE falls below 32 DEGREES Fahrenheit (0 degrees Celsius).

Frost wedging. Powerful form of PHYSICAL WEATHERING of ROCK, in which the expansion of water as it freezes in JOINTS or cracks shatters the rock into smaller pieces. Also known as frost shattering.

Fumarole. Crack in the earth's surface from which steam and other gases emerge. Fumaroles are found in volcanic areas and areas of GEOTHERMAL activity, such as Yellowstone National Park.

Functional region. Part of the earth's surface that is integrated or connected in a functional sense. A political unit such as a COUNTY, a METROPOLITAN statistical area, or an incorporated CITY is a functional region.

Funnel cloud. Narrow base of a TORNADO, between the bottom of a CUMULONIMBUS CLOUD and the ground, caused by the reduction of pressure at the center of the tornado. Devastation occurs as the funnel cloud moves rapidly along the ground. The cloud is dark because debris of all kinds has been sucked into the tornado. Most damage is caused by the strong swirling WINDS, but the low pressure at the center can cause buildings to explode. A WATERSPOUT also has a funnel cloud.

Fusion, nuclear. Collision and combining of two nuclei to form a single nucleus with less mass than the original nuclei, with a release of ENERGY equivalent to the mass reduction.

Fusion energy. Heat derived from the natural or human-induced union of atomic nuclei; in effect, the opposite of FISSION energy.

Gale. Strong WIND. On the BEAUFORT wind SCALE, gale force RANGES from 30 miles (50 km.) per hour (moderate) through fresh gale and strong gale, to a whole gale or STORM, when windspeeds are 48 to 55 knots (88 to 101 km.) per hour. At SEA, the progression is from blown sea spray to a foam-covered sea with very high WAVES. On land, a moderate gale means entire trees move; in a whole gale, trees are uprooted and considerable structural damage occurs.

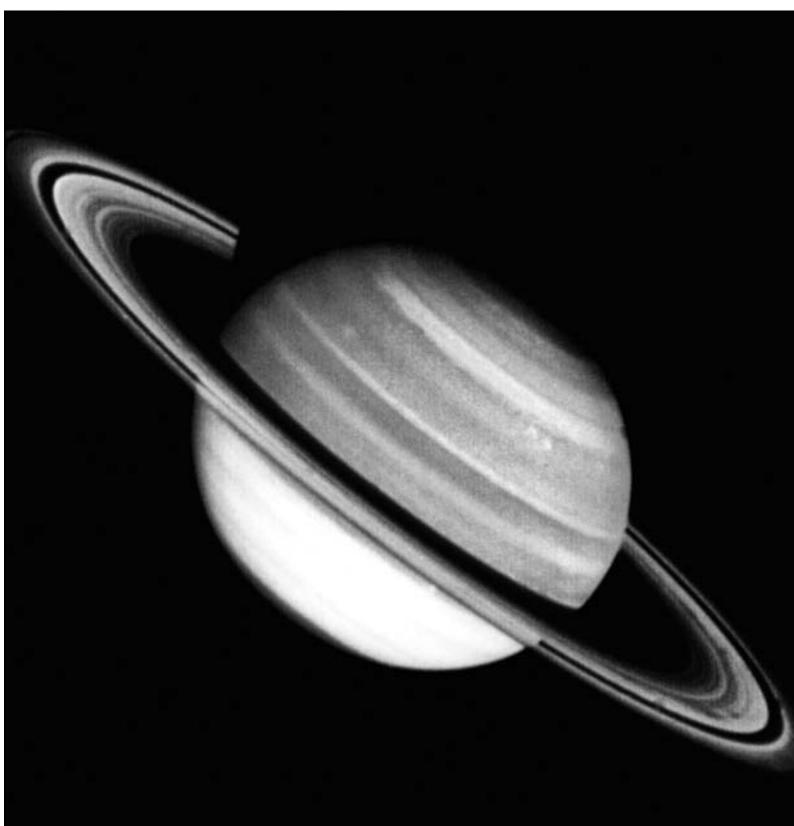
Gall's projection. MAP PROJECTION constructed by projecting the earth onto a cylinder that intersects the sphere at 45 DEGREES north and 45 degrees south LATITUDE. The resulting map has less distortion of area than the more familiar CYLINDRICAL PROJECTION of Mercator. See also MAP.

Gangue. Apparently worthless ROCK or earth in which valuable gems or MINERALS are found.

Gap. Steep VALLEY or GORGE cut by a STREAM as it flows through an area of hard ROCK. In some cases, the stream stops flowing or disappears, usually because of stream capture. The LANDFORM feature is then called a WIND GAP.

Garigue. VEGETATION cover of small shrubs found in Mediterranean areas. Similar to the larger *maquis.*

Gas giant. Large planetary body that is primarily composed of hydrogen



Best known for its spectacular rings, Saturn is one of four gas giant planets in the Solar System. (PhotoDisc) and helium, with minor amounts of other components; Jupiter, Saturn, Uranus, and Neptune are gas giants.

Gateway city. CITY whose physical LOCATION makes it a link between one COUNTRY and others, or between one REGION and others. A gateway city exercises control over a large area, because it commands the entry and exit rights and powers for a particular country or region. Most gateway cities are PORTS, many of which were formerly administrative centers for a colonial government. New York began as a small fur-trading outpost, but in the nineteenth century, it became a gateway for millions of immigrants from Europe to America. In colonial Brazil, Salvador was the gateway city through which more than three million slaves were brought from Africa to work on Portuguese-owned PLANTATIONS.

Gemstone. Any ROCK, MINERAL, or natural material that has the potential for use as personal adornment or ornament. Examples include diamonds, emeralds, rubies, and sapphires.

Gentrification. Phenomenon that occurs when the older housing stock of inner-CITY, working-class neighborhoods is purchased and renovated as a residential area for higher-income households. The new purchasers are attracted by the convenience of an inner-city LOCATION and lower prices, but gentrification displaces many of the older, original inhabitants.

Genus (plural, genera). Group of closely related species; for example, *Homo* is the genus of humans, and it includes the species *Homo sapiens* (modern humans) and *Homo erectus* (Peking Man, Java Man).

Geochronology. Study of the time SCALE of the earth; it attempts to develop methods that allow the scientist to reconstruct the past by dating events such as the formation of ROCKS.

Geodesy. Branch of applied mathematics that determines the exact positions of points on the earth's surface, the size and shape of the earth, and the variations of terrestrial GRAVITY and MAGNETISM.

Geoid. Figure of the earth considered as a MEAN SEA LEVEL surface extended continuously through the CONTINENTS.

Geologic map. MAP illustrating the age, structure, and DISTRIBUTION of ROCK units.

Geologic record. History of the earth and its life as recorded in successive layers of SEDIMENT and the FOSSIL specimens they contain.

Geologic terrane. Crustal block with a distinct group of ROCKS and structures resulting from a particular geologic history; assemblages of TERRANES form the CONTINENTS.

Geological column. Order of ROCK layers formed during the course of the earth's history.

Geomagnetic elements. MEASUREMENTS that describe the direction and intensity of the earth's MAGNETIC FIELD.

Geomagnetic poles. See MAGNETIC POLES.

Geomagnetism. External MAGNETIC FIELD generated by forces within the earth; this force attracts materials having similar properties, inducing them to line up (point) along field lines of force.

Geomorphic cycle. See CYCLE OF EROSION.

Geomorphology. Study of the origins of LANDFORMS and the processes of landform development.

Geophysics. Quantitative evaluation of ROCKS and surface features of the earth by electrical, gravitational, magnetic, radioactive, and elastic wave transmission and heat-flow techniques.

Geostationary orbit. ORBIT in which a SATELLITE appears to hover over one spot on the PLANET's EQUATOR; this procedure requires that the orbit be high enough that its period matches the planet's rotational period, and have no inclination relative to the equator; for Earth, the ALTITUDE is 22,260 miles (35,903 km.).

Geostrophic. Force that causes directional change because of the earth's ROTATION.

Geotherm. Curve on a TEMPERATURE-depth graph that describes how temperature changes in the subsurface.

Geothermal. Pertaining to the heat of the interior of a PLANET.

Geothermal power. Power having its source in the earth's internal heat.

Geyser. Type of HOT SPRING that periodically erupts steam and hot water. Geysers are surface expressions of vast underground circulation sys-

One of the most famous geysers in the world is Yellowstone National Park's Old Faithful, which owes its nickname to the clocklike regularity with which it erupts. (Digital Stock) tems, where constituents from underground ROCKS are dissolved in the hot fluids, carried to the surface, and deposited. The world's active thermal areas are natural laboratories where ORE-forming processes can be observed at first hand.

Glacial erratic. (U.S. Geological Survey)

Glacial erratic. ROCK that has been moved from its original position and transported by becoming incorporated in the ice of a GLACIER. Deposited in a new LOCATION, the rock is noteworthy because its geology is completely different from that of the surrounding rocks. Glacial erratics provide information about the direction of glacial movement and strength of the flow. They can be as small as PEBBLES, but the most interesting erratics are large boulders. Erratics become smoothed and rounded by the transport and EROSION.

Glaciation. This term is used in two senses: first, in reference to the cyclic widespread growth and advance of ICE SHEETS over the polar and high- to mid-LATITUDE REGIONS of the CONTINENTS; second, in reference to the effect of a GLACIER on the TERRAIN it transverses as it advances and recedes.

Mount Shuksan, in northern Washington's North Cascades National Park, has nine major glaciers, which have sculpted it to resemble peaks in the Swiss Alps. (Corbis)

Glacier. Tightly packed snowmass that grows larger as it receives more PRECIPITATION and moves forward—often with enough power to reshape land formations.

Glaciology. Scientific study of GLACIERS and ice.

Global Positioning System (GPS). Group of SATELLITES that ORBIT Earth every twenty-four hours, sending out signals that can be used to locate PLACES on Earth and in near-Earth orbits.

Global warming. Trend of Earth CLIMATES to grow increasingly warm as a result of the GREENHOUSE EFFECT. One of the most dramatic effects of global warming is the melting of the POLAR ICE CAPS and a consequent rise in the level of the world's OCEANS.

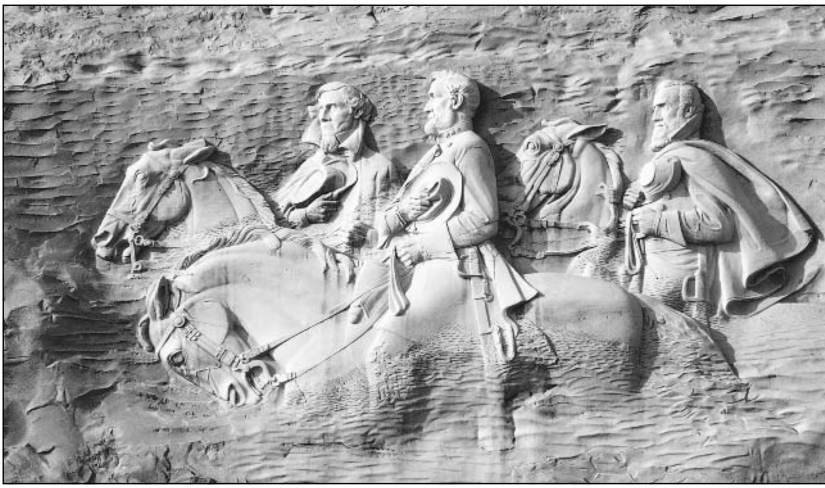
Gondwanaland. Hypothesized ancient CONTINENT in the SOUTHERN HEMISPHERE that geologists theorize broke into at least two large segments; one segment became India and pushed northward to collide with the Eurasian LANDMASS, while the other, Africa, moved westward. Australia and Antarctica were also part of Gondwanaland.

Gorge. Steeply walled CANYON or section of a canyon.

The Columbia River Gorge is a break in the Cascade Range through which the Columbia River passes. The Lewis and Clark Expedition reached the gorge in 1806. (PhotoDisc)

Graben. Roughly symmetrical crustal depression formed by the lowering of a crustal block between two NORMAL FAULTS that slope toward each other.

Granite. Coarse-grained, commonly light-colored PLUTONIC IGNEOUS ROCK composed primarily of two FELDSPARS (plagioclase and orthoclase) and QUARTZ, with variable amounts of dark MINERALS.



Stone Mountain in northwestern Georgia, has a monumental relief carved into its granite northern face. (PhotoDisc)

Granules. Small grains or pellets.

Grassland. Two of Earth's major BIOMES, grasslands cover about a quarter of the world's land surface. Because the temperate grassland regions constitute the PLANET's richest SOILS, they are intensely farmed and grazed, and only small patches of natural grassland remain. Tropical grasslands are usually known as SAVANNA.

Gravimeter. Device that measures the attraction of GRAVITY.

Gravitational differentiation. Separation of MINERALS, elements, or both as a result of the influence of a gravitational field wherein heavy phases sink or light phases rise through a melt.

Gravity. Natural attractive force exerted by Earth on objects on or near its surface.

Great circle. Largest circle that goes around a sphere. On the earth, all lines of LONGITUDE are parts of great circles; however, the EQUATOR is the only line of LATITUDE that is a great circle.

Green mud. SOILS that develop under conditions of excess water, or waterlogged soils, can display colors of gray to blue to green, largely because of chemical reactions involving iron. Fine CLAY soils and muds in areas such as BOGS or ESTUARIES can be called green mud. This soil-forming process is called gleization.

Greenhouse effect. Trapping of the SUN's rays within the earth's ATMOSPHERE, with a consequence rise in TEMPERATURES that leads to GLOBAL WARMING.

Greenhouse effect gets its name because clouds and gases of the lower atmosphere trap surface radiation in a manner similar to that of buildings called greenhouses, such as this greenhouse for tree seedlings. (PhotoDisc)

Greenhouse gas. Atmospheric gas capable of absorbing electromagnetic radiation in the infrared part of the spectrum.

Greenwich mean time. Also known as universal time, the solar mean time on the MERIDIAN running through Greenwich, England—which is used as the basis for calculating time throughout most of the world.

Grid. Pattern of horizontal and vertical lines forming squares of uniform size.

Gross domestic product. Value representing the total value of all goods, food, MINERALS, and services produced in a particular COUNTRY in one year. This total value usually is divided by the total POPULATION of the country, so that the figure given is the gross domestic product (GDP) per capita. The GDP is often used to compare the standard of living in different countries. For high-income economies, some economists and other researchers prefer to use the gross national product per capita.

Gross migration. Total number of migrants moving into and out of a REGION. The balance between these two MIGRATION streams is called NET MIGRATION.

Groundwater. Water that occurs beneath the surface of the earth, as opposed to SURFACE WATER that occurs in RIVERS and LAKES. Most groundwater comes from PRECIPITATION, when water percolates through soil or ROCK until it is stopped by an impervious rock layer called an aquiclude. The rocks that store groundwater in this way are called AQUIFERS. WELLS are drilled to pump groundwater to the surface for IRRIGATION and for human consumption. Groundwater accounts for about 0.6 percent of the earth's total HYDROSPHERE.

Groundwater movement. Flow of water through the subsurface, known as groundwater movement, obeys set principles that allow hydrologists to predict flow directions and rates.

Groundwater recharge. Water that infiltrates from the surface of the earth downward through SOIL and ROCK pores to the WATER TABLE, causing its level to rise.

Growth pole. LOCATION where high-growth economic activity is deliberately encouraged and promoted. Governments often establish growth poles by creating industrial parks, open cities, special economic zones, new TOWNS, and other incentives. The plan is that the new industries will further stimulate economic growth in a cumulative trend. Automobile plants are a traditional form of growth industry but have been overtaken by high-tech industries and BIOTECHNOLOGY. In France, the term "technopole" is used for a high-tech growth pole. A related concept is SPREAD EFFECTS.

Guano. Fossilized bird excrement, found in abundance on some COASTS or ISLANDS, notably Nauru in the Pacific.

Guest workers. People who migrate temporarily to another COUNTRY for jobs. Much of the money they earn is sent back to families in the HOMELAND. Guest workers are a form of economic migrants, but the emphasis is on the temporary nature of their residence in the new country. After World War II, a shortage of industrial and factory workers led Germany to invite guest workers from Greece, Italy, Yugoslavia, and Turkey to provide labor in the newly rebuilt factories, or to fill low-paid positions. France has many guest workers from northern African countries. Guest workers pose social problems in the new country. Their presence is sometimes resented by nationals. Most guest workers are young men, which can lead to social problems with prostitution, for example. Guest workers tend to form residential ENCLAVES in low-rent areas of a CITY, creating a kind of ghetto.

Gulf. Large OCEAN INLET. "Gulf" is not a precise term but it is usually applied to inlets larger than BAYS.

Guyot. Drowned volcanic ISLAND with a flat top caused by WAVE EROSION or coral growth. A type of SEAMOUNT.

Gyre. Large semiclosed circulation patterns of OCEAN CURRENTS in each of the major OCEAN BASINS that move in opposite directions in the Northern and Southern hemispheres. There are five gyres in the world's oceans.

Haff. Term used for various WETLANDS or LAGOONS located around the southern end of the Baltic Sea, from Latvia to Germany. Offshore BARS of SAND and shingle separate the haffs from the open SEA. One of the largest is the Stettiner Haff, which covers the BORDER REGION between Germany and Poland and is separated from the Baltic by the low-lying ISLAND of Usedom. The Kurisches Haff (in English, the Courtland Lagoon) is located on the Lithuanian border.

Hamlet. Loose term for a human SETTLEMENT that would be considered smaller than a VILLAGE.

Harbor. INLET, or protected body of water, that serves as an anchorage for shipping or small boats.

Harmonic tremor. Type of EARTHQUAKE activity in which the ground undergoes continuous shaking in response to subsurface movement of MAGMA.

Headland. Elevated land projecting into a body of water.

Headwaters. Source of a RIVER. Also called headstream.

Heat index. Measure combining TEMPERATURE and RELATIVE HUMIDITY to indicate an apparent or sensible temperature, which is a guide to the danger of overexertion in certain WEATHER conditions.

Heat sink. Term applied to Antarctica, whose cold CLIMATE causes warm AIR masses flowing over it to chill quickly and lose ALTITUDE, affecting the entire world's WEATHER.

Hemisphere. Geometrical term for half of a sphere. All spherical celestial objects, such as PLANETS and stars, have NORTHERN and SOUTHERN HEMISPHERES divided by the bodies' EQUATORS. Hemisphere defined by MERIDIANS are more arbitrary. The earth is generally regarded as being divided into EASTERN and WESTERN HEMISPHERES, but their REGIONS are not precisely defined.

Heterosphere. Major realm of the ATMOSPHERE in which the gases hydrogen and helium become predominant.

High-frequency seismic waves. EARTHQUAKE WAVES that shake the ROCK through which they travel most rapidly.

High island. See CONTINENTAL ISLAND.

Hill. Term loosely applied to an elevated mass of land that would be considered smaller than a MOUNTAIN. In contrast to a PEAK, a hill usually has a smooth SUMMIT.

Hillock. Small natural HILL. A similar but smaller feature is a hummock. There is no standard definition for these terms.

Hinterland. Area that surrounds a CITY and relies on the city for goods and services. The city, in turn, may draw RESOURCES from its hinterland. From the German word for "country behind."

Histogram. Bar graph in which vertical bars represent frequency and the horizontal axis represents categories. A POPULATION PYRAMID, or age-sex pyramid, is a histogram, as is a CLIMOGRAPH.

Historical inertia. Term used by economic geographers when heavy industries, such as steelmaking and large manufacture, that require huge capital investments in land and plant continue in operation for long periods, even after they become out of date, uncompetitive, or obsolete.

Hoar frost. Similar to DEW, except that moisture is deposited as ice crystals, not liquid dew, on surfaces such as grass or plant leaves. When moist AIR cools to saturation level at TEMPERATURES below the freezing point, CONDENSATION occurs directly as ice. Technically, hoar frost is not the same as frozen dew, but it is difficult to distinguish between the two.

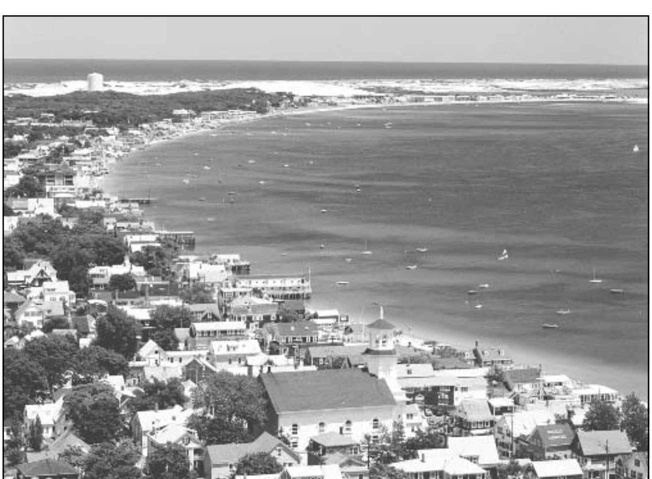
Hogback. Steeply sloping homoclinal RIDGE, with a slope of 45 DEGREES or more. The angle of the slope is the same as the dip of the ROCK STRATA. These LANDFORMS develop in REGIONS where the underlying rocks, usually SEDIMENTARY, have been folded into anticlinal ridges and synclinal VALLEYS. Differential EROSION causes softer rock layers to wear away more rapidly than the harder layers of rock that form the hogback ridge. A similar feature with a gentler slope is called a CUESTA.

Holocene. Name for the current, or modern, geological EPOCH. It began around ten thousand years ago, after the PLEISTOCENE.

Homeland. CULTURE REGION to which a group of humans have an emotional attachment. ETHNIC GROUPS are usually identified with a homeland, which comprises a physical LANDSCAPE and the historical events that occurred there.

Homosphere. Lower part of the earth's ATMOSPHERE. In this area, 60 miles (100 km.) thick, the component gases are uniformly mixed together, largely through WINDS and turbulent AIR CURRENTS. Above the homosphere is the REGION of the atmosphere called the HETEROSPHERE. There, the individual gases separate out into layers on the basis of their molecular weight. The lighter gases, hydrogen and helium, are at the top of the heterosphere.

Hook. A long, narrow deposit of SAND and SILT that grows outward into the OCEAN from the land is called a SPIT or sandspit. A hook forms



Cape Cod, Massachusetts, is the most famous spit and hook in the United States. (PhotoDisc) when currents or WAVES cause the deposited material to curve back toward the land. Cape Cod is the most famous spit and hook in the United States.

Horizon, true. GREAT CIRCLE of the celestial sphere. It is formed by the intersection of the celestial sphere and a plane through the center of the earth, and is perpendicular to the zenith-nadir line. The true horizon is not the same as the visible HORIZON, which is the line where earth and sky appear to a viewer to meet. Also known as rational horizon.

Horizon, visible. Line where the sky seems to meet the SEA or land. The ALTITUDE of the observer affects the distance between that person and the visible horizon: A person standing on a MOUNTAIN perceives the horizon as being a much greater distance away than a person at SEA LEVEL. Also called sensible or rational horizon.

Horse latitudes. Parts of the OCEANS from about 30 to 35 DEGREES north or south of the EQUATOR. In these latitudes, AIR movement is usually light WINDS, or even complete calm, because there are semipermanent high-pressure cells called ANTICYCLONES, which are marked by dry subsiding air and fine clear WEATHER. The atmospheric circulation of an anticyclone is divergent and CLOCKWISE in the NORTHERN HEMISPHERE, so to the north of the horse latitudes are the westerly winds and to the south are the northeast TRADE WINDS. In the SOUTHERN HEMISPHERE, the circulation is reversed, producing the easterly winds and the southeast trade winds. It is believed that the name originated because when ships bringing immigrants to the Americas were becalmed for any length of time, horses were thrown overboard because they required too much FRESH WATER. Also called the CALMS OF CANCER.

Horst. FAULT block or piece of land that stands above the surrounding land. A horst usually has been uplifted by tectonic forces, but also could have originated by downward movement or lowering of the adjacent lands. Movement occurs along the parallel faults on either side of a horst. If the land is downthrown instead of uplifted, a VALLEY known as a GRABEN is formed. "Horst" comes from the German word for horse, because the flat-topped feature resembles a vaulting horse used in gymnastics.

Horticulture. Cultivation of plants in gardens or orchards to produce food for one's own consumption or for sale. Horticulture is a form of commercial AGRICULTURE and is usually found near large cities, where there is a ready market for fresh produce. "Market gardening" is a similar term.

Hot spot. PLACE on the earth's surface where heat and MAGMA rise from deep in the interior, perhaps from the lower MANTLE. Erupting VOLCANOES may be present, as in the formation of the Hawaiian Islands. More commonly, the heat from the rising magma causes GROUNDWATER to form HOT SPRINGS, GEYSERS, and other thermal and HYDRO-

Landsat image of the big island of Hawaii, which rests on a plate that is moving across a hot spot. (U.S. Geological Survey)

thermal features. Yellowstone National Park is located on a hot spot. Also known as a MANTLE PLUME.

Hot spring. SPRING where hot water emerges at the earth's surface. The usual cause is that the GROUNDWATER is heated by MAGMA. A GEYSER is a special type of hot spring at which the water heats under pressure

Mammoth Hot Springs in Yellowstone National Park comprises about seventy separate springs, which maintain water temperatures between 60 and 175 degrees Fahrenheit (15 to 80 degrees Celsius). (Digital Stock) and that periodically spouts hot water and steam. Old Faithful is the best known of many geysers in Yellowstone National Park. In some countries, GEOTHERMAL ENERGY from hot springs is used to generate electricity. Also called thermal spring.

Huerta. Irrigated orchard or agricultural parcel of land in southern Spain. The MEDITERRANEAN CLIMATE, IRRIGATION, and intensive labor make the Spanish huertas productive. Typical crops include grains such as corn and wheat, citrus, peaches, nuts, grapes, and dates; beef cattle are raised also. If the irrigated land is used mainly for the production of fodder crops, it may be called a vega.

Humid-midlatitude. Land area with average TEMPERATURE of the coldest month less than 64 DEGREES Fahrenheit (18 degrees Celsius) but at least eight months with average monthly temperatures greater than 50 degrees Fahrenheit (10 degrees Celsius); this area has no dry season.

Humidity. Water vapor in the earth's ATMOSPHERE. Concentrated in the lower 1 mile (1.6 km.) of the TROPOSPHERE. It may be measured as ABSOLUTE HUMIDITY (in grams per cubic meter), as specific humidity (in grams per kilogram of AIR), or, most commonly, as RELATIVE HUMIDITY—a percentage that represents the amount of water vapor in the air at a given TEMPERATURE, compared with the amount the air could contain if it were saturated. High humidity causes discomfort because evaporative cooling is hampered.

Hummock. See HILLOCK.

Hummocky. TOPOGRAPHY characterized by a slope composed of many irregular mounds (hummocks) that are produced during sliding or flowage movements of earth and ROCK.

Humus. Uppermost layer of a SOIL, containing decaying and decomposing organic matter such as leaves. This produces nutrients, leading to a fertile soil. Tropical soils are low in humus, because the rate of decay is so rapid. Soils of GRASSLANDS and DECIDUOUS FOREST develop thick layers of humus. In a SOIL PROFILE, the layer containing humus is the O Horizon.

Hunting and gathering. Preagricultural ECONOMY based on finding and harvesting edible forms of wildlife and plants.

Hurricane. North American term for a tropical rotating STORM with low pressure in the center and WIND speeds in excess of 74 miles (64 knots/119 km.) per hour. Elsewhere called a TROPICAL CYCLONE or TYPHOON. Hurricanes develop near the EQUATOR over tropical OCEANS, usually in the summer when the water is warmest. In general, the path in the NORTHERN HEMISPHERE is to the northwest, and in the SOUTHERN HEMISPHERE to the southwest. The diameter of a hurricane can vary from 50 to 500 miles (80-800 km.), with wind speed increasing toward the center. At the center is the quiet EYE, a zone 10 to 25 miles (16-40 km.) in diameter, where there is no wind, pressure is extremely low, and the sky is clear. Surrounding the eye is the eye wall, where tall

Hurricane winds can reach strengths that not only bend trees but pull them out of the ground by their roots. (PhotoDisc)

CUMULONIMBUS CLOUDS swirl upward, rain falls heavily, and wind speeds are greatest. A hurricane has a life of about one week, although it loses ENERGY as soon as it crosses from ocean to land. Wind damage to property is considerable in a hurricane, but the greatest loss of life is caused by the resulting flooding. Torrential rain leads to swollen RIVERS; another factor is the STORM SURGE that originates when winds raise the ocean level to as much as 22 feet (7 meters) above the normal high-tide level. Parts of low-lying Bangladesh and India have suffered huge losses of life from these storms, which are called CYCLONES there. Hurricanes begin as TROPICAL DEPRESSIONS, which have a wind speed of up to 37 miles (61 km.) per hour. When wind speeds reach 38 to 70 miles (63 to 117 km.) per hour, the storm is classified as a TROPICAL STORM and a name is assigned. Tropical storms are watched carefully because they can develop into full hurricanes. It is thought that GLOBAL WARMING will lead to more frequent hurricanes, occurring in a wider area.

Hydroelectric power. Electricity generated when falling water turns the blades of a turbine that converts the water's potential ENERGY to mechanical energy. Natural WATERFALLS can be used, but most hydroelectric power is generated by water from DAMS, because the flow of water from a dam can be controlled. Hydroelectric generation is a RENEWABLE, clean, cheap way to produce power, but dam construction inundates land, often displacing people, who lose their homes, VILLAGES, and farmland. Aquatic life is altered and disrupted also; for example, Pacific salmon cannot return upstream on the Columbia River to their spawning REGION. In a few coastal PLACES, TIDAL ENERGY is used to generate hydroelectricity; La Rance in France is the oldest successful tidal power plant.

Hydrography. Surveying of underwater features or those parts of the earth that are covered by water, especially OCEAN depths and OCEAN CURRENTS. Hydrographers make MAPS and CHARTS of the ocean floor and COASTLINES, which are used by mariners for NAVIGATION. For centuries, mariners used a leadline, a long rope with a lead weight at the bottom. The line was thrown overboard and the depth of water measured. The unit of MEASUREMENT was FATHOMS (6 feet/1.8 meters), which is one-thousandth of a NAUTICAL MILE. The invention of sonar (underwater echo sounding) has enabled mapping of large areas, and hydrographers currently use both television cameras and SATELLITE data.

Hydrologic cycle. Continuous circulation of the earth's HYDROSPHERE, or waters, through EVAPORATION, CONDENSATION, and PRECIPITATION. Other parts of the hydrologic cycle include RUNOFF, INFILTRATION, and TRANSPIRATION.

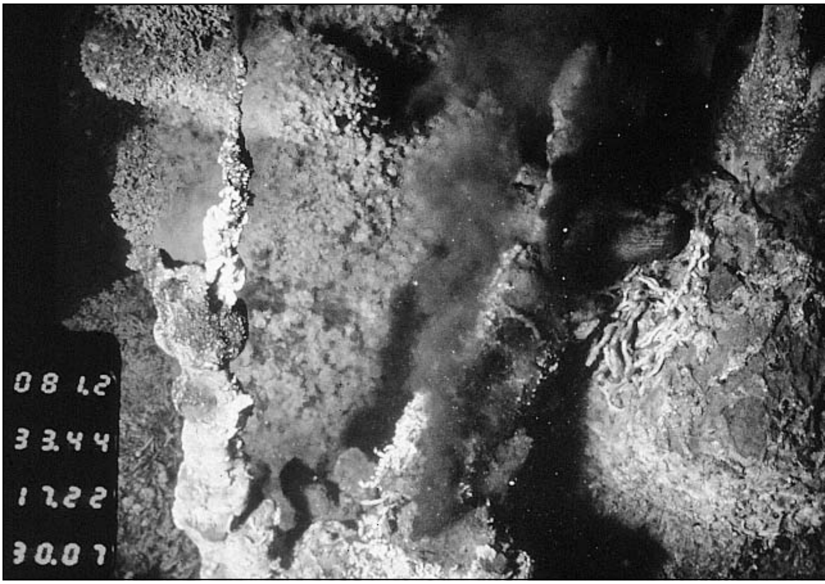
Hydrology. Scientific study of all aspects of water, especially the operation of the various parts of the HYDROLOGIC CYCLE. Hydrologists are concerned with water at or near the earth's surface; oceanographers study the waters of the OCEAN. To study the relationship between water and the living ENVIRONMENT, a hydrologist needs to know botany, geology, chemistry, SOIL science, and computer modeling. Hydrologists carry out research related to DAM construction; FLOOD CONTROL; agricultural developments, including irrigated farming; HYDROELECTRIC POWER generation; ACID RAIN and its impacts; disposal of solid and liquid wastes; and recreational facilities. SATELLITE imagery is used widely in modern hydrology.

Hydrosphere. All the waters of the earth, which comprise more than 300 million cubic miles (approximately 1.3 billion cubic km.). More than 97 percent of the hydrosphere is contained in the OCEANS; ICE SHEETS and GLACIERS make up more than 2 percent of the total. Freshwater LAKES and RIVERS account for only 0.0091 percent of the earth's hydrosphere.

Hydrostatic pressure. Pressure imposed by the weight of an overlying column of water.

Hydrothermal. Characterizing any process involving hot GROUNDWATER or MINERALS formed by such processes.

Hydrothermal vents. Areas on the OCEAN floor, typically along FAULT LINES or in the vicinity of undersea VOLCANOES, where water that has percolated into the ROCK reemerges much hotter than the surround-



Hydrothermal vent with "black smokers," where plumes of superheated water meet colder water and dark minerals begin to precipitate out and form "chimneys." (National Oceanic and Atmospheric Administration)

ing water; such heated water carries various dissolved MINERALS, including metals and sulfides.

Hyetograph. Chart showing the DISTRIBUTION of RAINFALL over time. Typically, a hyetograph is constructed for a single STORM, showing the amount of total PRECIPITATION accumulating throughout the period. A hyetograph shows how rainfall intensity varies throughout the duration of a storm.

Hygrogram. Record made by a HYGROGRAPH. Under natural conditions, a hygrogram shows the increase of HUMIDITY in the early morning and the decrease each DAY as the TEMPERATURE rises. If a constant humidity needs to be maintained, a hygrograph is a way to monitor this factor.

Hygrograph. HYGROMETER that produces a record of RELATIVE HUMIDITY in the form of a graph or chart. A pen moves over a graph paper that is attached to a rotating cylinder. The cylinder can rotate once in 24 hours or once a week. The recording of HUMIDITY is based on the property of human hair to increase in length as humidity rises (known in daily life as a "bad hair day"). As the hair in the hygrograph absorbs moisture or dries out, it causes the pen to change position on the graph paper. Museums, especially art museums, often have a hygrograph to check on conditions for the delicate objects they display. When there are two pens, the second recording TEMPERATURE, the instrument is called a thermohygrograph.

Hygrometer. Instrument for measuring the RELATIVE HUMIDITY of AIR, or the amount of water vapor in the ATMOSPHERE at any time.

Hygrophyte. Plant that is adapted to living in wet conditions, usually with its roots permanently wet. Hygrophytic trees, such as the SWAMP cypress, have trunks that flare out into buttresses at the base to stabilize the tall tree. Other plants, like reeds and water lilies, have soft stems that can sway with the water movement.

Hypocenter. Central underground LOCATION of an earth tremor; also called the focus.

Hypsometer. Instrument used for measuring ALTITUDE (height above SEA LEVEL), using boiling water that circulates around a THERMOMETER. Since ATMOSPHERIC PRESSURE falls with increased altitude, the boiling point of water is lower. The hypsometer relies on this difference in boiling point to calculate ELEVATION. A more common instrument for measuring altitude is the ALTIMETER.

Ice age. PERIOD of geologic time when large parts of the earth's land surface were covered with ice and GLACIERS, because of a lowering of atmospheric TEMPERATURE. There have been several ice ages throughout Earth's history. The most recent began around two million years ago. See PLEISTOCENE.

Ice blink. Bright, usually yellowish-white glare or reflection on the underside of a CLOUD layer, produced by light reflected from an ice-covered surface such as pack ice. A similar phenomenon of reflection from a snow-covered surface is called snow blink.

Ice-cap climate. Earth's most severe CLIMATE, where the mean monthly TEMPERATURE is never above 32 DEGREES Fahrenheit (0 degrees Celsius). This climate is found in Greenland and Antarctica, which are high PLATEAUS, where KATABATIC WINDS blow strongly and frequently. At these high LATITUDES, INSOLATION (SOLAR ENERGY) is received for a short period in the summer months, but the high reflectivity of the ice and SNOW means that much is reflected back instead of being absorbed by the surface. No VEGETATION can grow, because the LANDSCAPE is permanently covered in ice and snow. Because AIR temperatures are so cold, PRECIPITATION is usually less than 5 inches (13 centimeters) annually. The POLES are REGIONS of stable, high-pressure air, where dry conditions prevail, but strong winds that blow the snow around are common. In the KOEPPEN CLIMATE CLASSIFICATION, the ice-cap climate is signified by the letters *EF.*

Ice caps. Small ICE SHEETS circular in shape covering areas of less than 19,300 square miles (50,000 sq. km.). See also POLAR ICE CAP.

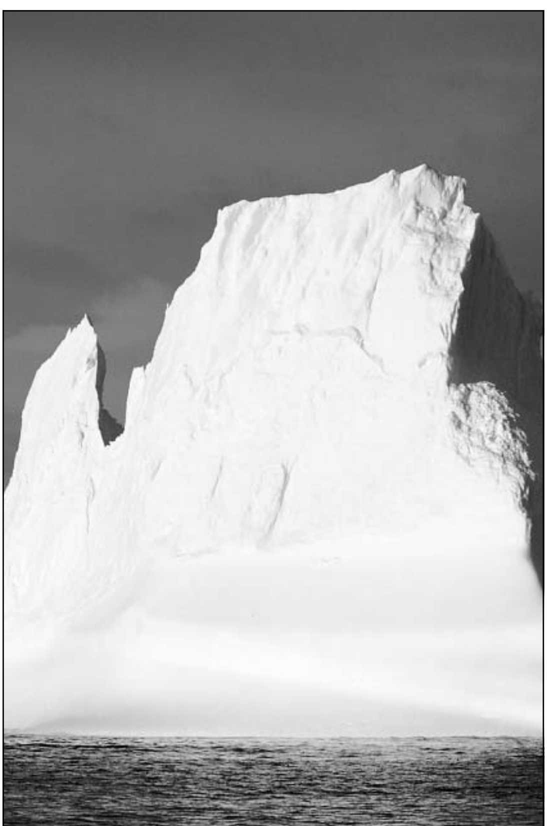
Ice field. Similar to an ICE CAP, but elongated instead of forming a dome shape. Isolated PEAKS or RIDGES can protrude above the ice field. The best and largest example is the ice field in Patagonia in the Andes mountains of Argentina and Chile.

Ice sheet. Huge CONTINENTAL GLACIER. The only ice sheets remaining cover most of Antarctica and Greenland. At the peak of the last ICE AGE, around eighteen thousand years ago, ice covered as much as one-third of the earth's land surfaces. In the NORTHERN HEMISPHERE, there were two great ice sheets—the Laurentide ice sheet, covering North America, and the Scandinavian ice sheet, covering northwestern Europe and Scandinavia.

Ice shelf. Portion of an ICE SHEET extending into the OCEAN.

Ice storm. STORM characterized by a fall of freezing rain, with the formation of glaze on Earth objects.

Iceberg. Large mass of freshwater ice floating in the OCEAN, having broken off (calved) from the SNOUT of a GLACIER or the edge of an ICE SHEET. CALVING produces tens of thousands of icebergs each year around the margins of Greenland and Antarctica during the warmest summer months. Icebergs vary in height from a few feet to the height of a ten-story building and can persist for years. Depending on the shape of the iceberg, 80 to 90 percent of its total mass is submerged. Icebergs are moved by WAVES, WINDS, and OCEAN CURRENTS. They can be eroded by waves; more commonly, they melt as they move into warmer waters. Icebergs from Greenland were observed as far south as Bermuda early in the twentieth century. In the North Atlantic Ocean, icebergs from western Greenland are moved south by the Labrador Current and enter shipping lanes, where they pose a severe danger to vessels on the busy route between North America and Europe. When the steamship *Titanic*, a supposedly unsinkable vessel, collided with an iceberg in 1912, it sank so quickly that fifteen hundred passengers and crew members were drowned or perished in the icy waters. Today, radar and sonar can give early warning of iceberg danger to ships.



Giant iceberg. (PhotoDisc)

Oceanographers, the U.S. Coast Guard, and mariners monitor and track icebergs that approach shipping lanes.

Icefoot. Long, tapering extension of a GLACIER floating above the seawater where it enters the OCEAN. Eventually, it breaks away and forms an ICEBERG.

Igneous. From the Latin *ignis* (fire), a term referring to ROCKS formed from the molten state or to processes that form such rocks.

Igneous rock. ROCKS formed when molten material or MAGMA cools and crystallizes into solid rock. The type of rock varies with the composition of the magma and, more important, with the rate of cooling. Rocks that cool slowly, far beneath the earth's surface, are igneous INTRUSIVE ROCKS. These have large crystals and coarse grains. GRANITE is the most typical igneous intrusive rock. When cooling is more rapid, usually closer to or at the surface, finer-grained igneous EXTRUSIVE ROCKS such as rhyolite are formed. If the magma flows out to the surface as LAVA, it may cool quickly, forming a glassy rock called obsidian. If there is gas in the lava, rocks full of holes from bubbles of escaping gases form; PUMICE and BASALT are common igneous extrusive rocks.

Immigration. Moving of new residents into an area on a permanent basis. The United States was the destination of many twentieth century immigrants. See also EMIGRATION.

Impact crater. Generally circular depression formed on the surface of a

The Barringer Meteor Crater in northern Arizona was the first meteor-impact site identified on Earth. Estimated to be more than twenty-five thousand years old, the crater is about six hundred feet (180 meters) deep and about 3,800 feet (1.2 km.) in diameter. (PhotoDisc)

PLANET by the impact of a high-velocity projectile such as a METEORITE, ASTEROID, or COMET.

Impact volcanism. Process in which major impact events produce huge CRATERS along with MAGMA RESERVOIRS that subsequently produce volcanic activity. Such cratering is clearly visible on the MOON, Mars, Mercury, and probably Venus. It is assumed that Earth had similar craters, but EROSION has erased most of the evidence.

Imperialism. Acquisition and retention of a colonial empire. Ancient empires included the Greek and Roman empires. More recently, empires in Europe, the Americas, and Africa were controlled by such European powers as Spain, Great Britain, France, and Russia.

Impervious rock. Also known as impermeable rock, materials through which water cannot pass. ROCKS through which water can pass are called pervious. Solid or massive GRANITE, for example, is impervious. Nevertheless, a granite outcrop may be pervious because of the presence of small cracks called JOINTS, or because of FISSURES in the rock. Water could pass through the outcrop along these openings. Most CLAYS are impervious.

Import substitution. Economic process in which domestic producers manufacture or supply goods or services that were previously imported or purchased from overseas and foreign producers.

Index fossil. Remains of an ancient organism that are useful in establishing the age of ROCKS; index fossils are abundant and have a wide geographic DISTRIBUTION, a narrow stratigraphic RANGE, and a distinctive form.

Indian summer. Short period, usually not more than a week, of unusually warm WEATHER in late October or early November in the NORTHERN HEMISPHERE. Before the Indian summer, TEMPERATURES are cooler and there can be occurrences of FROST. Indian summer DAYS are marked by clear to hazy skies and calm to light WINDS, but nights are cool. The weather pattern is a high-pressure cell or ridge located for a few days over the East Coast of North America. The name originated in New England, referring to the practice of NATIVE AMERICANS gathering foods for winter storage over this brief spell. Similar weather in England is called an Old Wives' summer.

Indigenous people. Native inhabitants of a REGION; the aboriginal peoples.

Industrial Revolution. Change of a society from a RURAL and agricultural lifestyle to one in which most people earn their living in the industrial or secondary sector of the ECONOMY. MIGRATION from rural VILLAGES to URBAN SETTLEMENTS accompanies this change. The first Industrial Revolution began in England in the early eighteenth century. Technological advances in iron smelting, and later steel production, were accompanied by the invention of the steam engine. This provided a source of power for many new types of machinery in spinning and weaving and the locomotive and related industries. The Industrial Revolution spread from Great Britain to the CONTINENT of Europe and, in the late nineteenth century, to the United States.

Industrialization. Change from an agricultural society or agricultural ECONOMY to one that derives most of its income from industrial production. The INDUSTRIAL REVOLUTION began in Great Britain in the eighteenth century and spread to many other countries. URBAN SETTLEMENTS grew dramatically in size as a result of the demand for labor in industrial establishments.

Infant mortality. DEMOGRAPHIC MEASURE calculated as the number of deaths in a year of infants, or children under one year of age, compared with the total number of live births in a COUNTRY for the same year. Low-income countries have high infant mortality rates, more than one hundred infant deaths per thousand.

Infauna. Organisms that live in the seafloor.

Infiltration. Movement of water into and through the SOIL.

Informal economy. Form of employment whereby a person sells goods or services without a government license, often on the streets. This is especially common in low-income economies and in URBAN AREAS where unemployment is high. Recent immigrants often resort to this means of livelihood.

Informal sector. Economic activities conducted without official regulation or control. Street vendors who operate without a permit are part of the informal sector, as are street performers and beggars. See also INFORMAL ECONOMY.

Informal settlements. See SQUATTER SETTLEMENTS.

Infrastructure. Man-made bases of a society, such as road networks, power lines, airports, schools, hospitals, railroads, and police services.

Initial advantage. In terms of economic DEVELOPMENT, not all LOCATIONS are suited for profitable investment. Some locations offer initial advantages, including an existing skilled labor pool, existing consumer markets, existing plants, and situational advantages. These advantages can also lead to clustering of a number of industries at a particular location and to further economic growth, which will provide the preconditions of initial advantage for further economic development.

Inlet. Any recess along a SHORELINE of a larger body of water. Specific terminology is not precise, but a BAY is generally larger than a COVE, and a GULF is larger than both.

Inlier. REGION of old ROCKS that is completely surrounded by younger rocks. These are often PLACES where ORES or MINERALS are found in commercial quantities.

Inner core. The innermost layer of the earth; the inner core is a solid ball with a radius of about 900 miles.

Inselberg. Exposed rocky HILL in a DESERT area, made of resistant ROCKS, rising steeply from the flat surrounding countryside. There are many

Uluru, or Ayers Rock, in Australia is perhaps the world's best-known example of an inselberg. (Digital Stock)

inselbergs in Africa, but Uluru (Ayers Rock) in Australia is possibly the most famous inselberg. The word is German for "island mountain."

Insolation. ENERGY received by the earth from the SUN, which heats the earth's surface. The average insolation received at the top of the earth's ATMOSPHERE at an average distance from the Sun is called the SOLAR CONSTANT. Insolation is predominantly shortwave radiation, with wavelengths in the RANGE of 0.39 to 0.76 micrometers, which corresponds to the visible spectrum. Less than half of the incoming SOLAR ENERGY reaches the earth's surface—insolation is reflected back into space by CLOUDS; smaller amounts are reflected back by surfaces, absorbed, or scattered by the atmosphere. Insolation is not distributed evenly over the earth, because of Earth's curved surface. Where the rays are perpendicular, at the SUBSOLAR POINT, insolation is at the maximum. The word is a shortened form of incoming (or intercepted) SOLAR RADIATION.

Insular climate. Island climates are influenced by the fact that no PLACE is far from the SEA. Therefore, both the DIURNAL (daily) TEMPERATURE RANGE and the annual temperature range are small.

Insurgent state. STATE that arises when an uprising or guerrilla movement gains control of part of the territory of a COUNTRY, then establishes its own form of control or government. In effect, the insurgents create a state within a state. In Colombia, for example, the government and armed forces have been unable to control several REGIONS where insurgents have created their own domains. This is generally related to coca growing and the production of cocaine. Civilian farmers are unable to resist the drug-financed "armies."

Intensive subsistence agriculture. Practice whereby a small area of agricultural land produces an abundant crop, usually as a result of intensive human labor and the application of FERTILIZER. Countries of Asia where wet rice is grown practice intensive subsistence agriculture. The POPULATION pressure on the land is high, but the combination of high

TEMPERATURE, abundant RAINFALL, rich SOILS, and the productivity of rice as a crop enable large numbers of people to exist in this way. Terracing of hillsides to increase the available farming land is typical in these areas.

Intercropping. Growing of more than one crop in the same agricultural plot or field. Intercropping is commonly practiced by shifting cultivators. SUSTAINABLE AGRICULTURE uses intercropping as an alternative to pesticides.

Interfluve. Higher area between two STREAMS; the surface over which water flows into the stream. These surfaces are subject to RUNOFF and EROSION by RILL action and GULLYING. Over time, interfluves are lowered.

Interglacial. Period between two major advances of glacial ice. There were as many as eighteen expansions of glacial ice during the PLEISTOCENE ice age EPOCH. Scientists usually identify four major GLACIATIONS, with intervening interglacials. The names for the glacial stages are slightly different in Europe from those used in North America.

Interlocking spur. STREAM in a hilly or mountainous REGION that winds its way in a sinuous VALLEY between the different RIDGES, slowly eroding the ends of the spurs and straightening its course. The view of interlocking spurs looking upstream is a favorite of artists, as colors change with the receding distance of each interlocking spur.

Intermediate rock. IGNEOUS ROCK that is transitional between a basic and a silicic ROCK, having a SILICA content between 54 and 64 percent.

Intermittent lake. LAKE that is sometimes dry. See also PERENNIAL LAKE.

Intermittent stream. RIVER that has periods when its flow stops. See also PERENNIAL STREAM.

Internal drainage. Flow of a RIVER into an internal LAKE or SWAMP, rather than out to the SEA. If the lake has no outlet, SALTS accumulate over time, making the lake saline. This feature is called a salina. The Great Salt Lake is an example of this type of an internal DRAINAGE BASIN. If EVAPORATION is high, a dry salt LAKEBED is eventually produced. DESERT drainage is usually internal, with EPHEMERAL STREAMS and RUNOFF draining downward to the lowest part of a depression. Also known as interior drainage.

Internal migration. Movement of people within a COUNTRY, from one REGION to another. Internal MIGRATION in high-income economies is often urban-to-RURAL, such as the migration to the SUN BELT in the United States. In low-income economies, rural-to-URBAN migration is more common.

International date line. Line in the Pacific Ocean where each new DAY begins as the earth rotates. Most of the line is on the MERIDIAN at 180 DEGREES west (also east) LONGITUDE, but some irregularities occur to accommodate the wishes of individual ISLANDS.

International migration. Movement of people across an international

BOUNDARY, usually on a permanent basis. The source REGIONS for international migration to the United States changed from Northern Europe to Southern and Central Europe in the nineteenth and early twentieth century, and to LATIN AMERICA, with an increasing component from Asian countries, in the late twentieth century. In 1998, the United Nations estimated that more than 100 million people lived outside their COUNTRY of origin. Although many were refugees or political migrants seeking asylum, most were economic migrants seeking a better life and higher standard of living.

Intertillage. Mixed planting of different seeds and seedling crops within the same SWIDDEN or cleared patch of agricultural land. Potatoes, yams, corn, rice, and bananas might all be planted. The planting times are staggered throughout the year to increase the variety of crops or nutritional balance available to the subsistence farmer and his or her family.

Intertropical convergence zone (ITCZ). Line at which WINDS converge near the EQUATOR, because constant high INSOLATION and twelve hours of daylight cause AIR in this REGION to heat and rise. The rising air expands and cools, producing a band of CLOUDS and frequent PRECIPITATION, often in the form of THUNDERSTORMS. The ITCZ corresponds to the THERMAL EQUATOR.

Intrusive rock. IGNEOUS ROCK which was formed from a MAGMA that cooled below the surface of the earth; it is commonly coarse-grained.

Inversion. See TEMPERATURE INVERSION.

Ionosphere. Layer of the earth's ATMOSPHERE in which there are a large number of ions, or electrically charged particles, chiefly nitrogen and oxygen. The ionosphere begins at a height of about 30 miles (50 km.) above the earth's surface and extends up to about 240 miles (400 km.), but it is most distinct at ALTITUDES above about 50 miles (80 km.). The ionosphere contains three distinct layers—the D layer, E layer, and F layer. These layers are important to radio broadcasts, because they re-

Interaction between solar wind and the earth's ionosphere produces glowing light effects known as the Aurora borealis in the Northern Hemisphere and Aurora australis in the Southern Hemisphere. (PhotoDisc) flect short-wave and AM radio transmission waves, especially at night; during the DAY, INSOLATION interferes with transmission. Ham radio operators use the bands of the ionosphere to communicate from their home base to distant parts of the earth. Television and FM signals are not affected by the ionosphere. The interaction of the SOLAR WIND with the earth's ionosphere produces glowing light effects known as the AURORA borealis and aurora australis.

Irredentism. Expansion of one COUNTRY into the territory of a nearby country, based on the residence of nationals in the neighboring country. Hitler used irredentist claims to invade Czechoslovakia, because small groups of German-speakers lived there in the Sudetenland. The term comes from Italian, referring to Italy's claims before World War I that all Italian-speaking territory should become part of Italy.

Irrigation. Bringing of water into drier REGIONS in order to use it for AGRICULTURE. Regions that have low RAINFALL or a long dry season use irrigation to ensure crop success. Modern TECHNOLOGY has enabled the construction of huge DAMS that produce HYDROELECTRIC POWER and also deliver water for irrigation by pipelines or CANALS. Surface irrigation includes flooding entire fields and furrow irrigation—running water between individual rows of plants. Alternatives are sprinkler irrigation systems—either an automatic traveling sprinkler system, in which a trailer moves a long arm of sprinklers slowly across a whole field, or a center-point pivot sprinkler that sprays a huge circular area—and drip irrigation, which delivers small amounts of water to each plant, using less water than other forms of irrigation. Water losses

Modern technology has made possible more efficient systems of irrigation, such as sprinklers, and with them, greater agricultural productivity. (PhotoDisc)

Furrow irrigation runs water between rows of plants. (PhotoDisc)

through EVAPORATION are a major concern with irrigation. The use of GROUNDWATER for irrigation has led to serious depletion of AQUIFERS worldwide. The Ogallala Aquifer in the United States lost more than 60 percent of its volume in the last third of the twentieth century and is not being replenished. Another major problem associated with irrigated agriculture is SALINIZATION.

Isallobar. Imaginary line on a MAP or meteorological chart joining PLACES with an equal change in ATMOSPHERIC PRESSURE over a certain time, often three hours. Isallobars indicate a pressure tendency and are used in WEATHER FORECASTING.

Islam. Religious faith with the second-largest number of adherents in the world, after Christianity. Its members are called Muslims. The word "Islam" means submission, obedience to the will of God. Islam recognizes the Old Testament prophets of the Bible but also believes that Muhammad (Mohammed) was the last of the prophets who brought God's words to earth. Muhammad was born in Medina, in what is now Saudi Arabia, in the seventh century. The holy book of Islam is the Qur'an (Koran). The two major branches of the Islamic faith are Sunni and Shia (Shiite).

Island. Piece of land, smaller than a CONTINENT, that is surrounded entirely by water. The world's largest island is Greenland. Islands are divided into four major types, depending on their formation: continental, oceanic, coral, and BARRIER. The isolation of islands has led to many interesting adaptations, and the study of island ECOSYSTEMS has been an exciting area of geography and biology. Charles Darwin's study of variations in finches on the Galapagos Islands was the foundation of his theories on evolution and NATURAL SELECTION. See also ARCHIPELAGO.

Island arc. Chain of VOLCANOES next to an oceanic TRENCH in the OCEAN BASINS; an oceanic PLATE descends, or subducts, below another oceanic plate at ISLAND arcs.

Islet. Small ISLAND.

Isobar. Imaginary line joining PLACES of equal ATMOSPHERIC PRESSURE. WEATHER MAPS show isobars encircling areas of high or low pressure. The spacing between isobars is related to the pressure gradient.

Isobath. Line on a MAP or CHART joining all PLACES where the water depth is the same; a kind of underwater CONTOUR LINE. This kind of map is a BATHYMETRIC CONTOUR.

Isoclinal folding. When the earth's CRUST is folded, the size and shape of the folds vary according to the force of compression and nature of the ROCKS. When the surface is compressed evenly so that the two sides of the fold are parallel, isoclinal folding results. When the sides or slopes of the fold are unequal or dissimilar in shape and angle, this can be an asymmetrical or overturned fold. See also ANTICLINE; SYNCLINE.

Isogonic line. Imaginary line drawn on a MAP connecting PLACES that have the same deviation from true north when a magnetic needle or COMPASS is used. This is necessary because the earth's NORTH MAGNETIC POLE does not correspond with the North Pole of 90 DEGREES north that represents true north or GRID north. Since the earth's magnetic north is not in a fixed position, isogonic lines vary over time. Aircraft pilots make use of isogonic lines.

Isohaline. Imaginary line on a CHART connecting points of equal SALINITY.

Isohel. Imaginary line drawn on a MAP connecting PLACES that receive an equal amount of sunshine.

Isohyet. Imaginary line drawn on a MAP connecting PLACES with the same amount of PRECIPITATION over a given time. Average annual RAINFALL is shown with isohyets. Seasonal precipitation maps are commonly constructed using isohyets. As a general guide, the isohyet marking 10 inches (250 millimeters) of annual precipitation is the lower limit beyond which crops cannot be grown without IRRIGATION.

Isoline. Imaginary line drawn on a MAP along which there is a constant value of the factor under study. Isolines commonly used by geographers include ISOTHERMS, ISOBARS, ISOHYETS, and CONTOUR LINES.

Isomagnetic charts. MAPS on which are traced curves, all the points of which have the same value in some magnetic element.

Isopleth. Imaginary line drawn on a MAP connecting points of equal value, based on calculations of various climatic variables such as average daily TEMPERATURE, average monthly PRECIPITATION, or number of FROST DAYS. An important isopleth to foresters is the TIMBERLINE, which marks an elevation above which it becomes too cold for trees to grow. In the KOEPPEN CLIMATE CLASSIFICATION, this is the BOREAL FOREST-TUNDRA BOUNDARY, which is calculated as PLACES where at least one month a year has an average temperature of at least 50 DEGREES Fahrenheit (10 degrees Celsius).

Isoseismal line. Line constructed after an EARTHQUAKE, showing areas of equal intensity of the earthquake. The intensity is calculated using seismographic records, along with study of the effects on buildings and surfaces. Intensity is a MEASUREMENT that combines data regarding ground shaking, features of the SEISMIC WAVES, geology, and other factors. If the earth's CRUST were completely uniform, the isoseismal curves would be concentric circles surrounding the EPICENTER of the earthquake, with the highest intensity at the center. Other factors, such as ROCK properties and positions of FAULTS, can cause an asymmetric pattern of isoseismal lines; at times, the epicenter is not located in the area of highest intensity. A modified MERCALLI SCALE is used in the United States to record earthquake intensity. It uses the numbers I (not felt) through XII (nearly total damage) to describe increasing intensity. Intensity is not the same as MAGNITUDE, which is commonly used to describe the size of an earthquake numerically.

Isostasy. Theory that the earth's CRUST maintains equilibrium because it is supported on a denser layer, at a depth of about 60 miles (100 km.). When LANDFORMS are weathered and eroded, material is removed from one PLACE, such as a mountain RANGE, and deposited in another, such as a FLOODPLAIN. On a large scale, material is eroded from CONTINENTS and deposited on OCEAN floors. Because of isostasy, however, the continents do not completely wear down. In response to the decrease in weight, the earth's crust rises. This process is called isostatic readjustment. It is similar to the fact that unloading a ship causes it to rise higher in the water. The removal of the great weight of glacial ice over the continents during the last ICE AGE led to isostatic UPLIFT, which is especially marked in Scandinavia. There, the rate of uplift is calculated at approximately 0.4 inch (1 centimeter) per year over the last few centuries.

Isotherm. Line joining PLACES of equal TEMPERATURE. A world MAP with isotherms of average monthly temperature shows that over the OCEANS, temperature decreases uniformly from the EQUATOR to the POLES, and higher temperatures occur over the CONTINENTS in summer and lower temperatures in winter because of the unequal heating properties of land and water.

Isotropic. Having properties the same in all directions; if elastic waves propagate at the same velocity in all directions, they are isotropic.

Isotropic surface. Hypothetical flat surface or PLAIN, with no variation in any physical attribute. An isotropic surface has uniform ELEVATION, SOIL type, CLIMATE, and VEGETATION. Economic geographic models study behavior on an isotropic surface before applying the results to the real world. For example, in an isotropic model, land value is highest at the CITY center and falls regularly with increasing distance from there. In the real world, land values are affected by elevation, water features, URBAN regulations, and other factors. The von Thuenen model of the Isolated State is based on a uniform plain or isotropic surface.

Isthmian links. Chains of ISLANDS between substantial LANDMASSES.

Isthmus. Narrow strip of land connecting two larger bodies of land. The Isthmus of Panama connects North and South America; the Isthmus of Suez connects Africa and Asia. Both of these have been cut by CANALS to shorten shipping routes.

ITCZ. See INTERTROPICAL CONVERGENCE ZONE.

Jebel. Arabic word for MOUNTAIN.

Jet stream. WINDS that move from west to east in the upper ATMOSPHERE, 23,000 to 33,000 feet (7,000-10,000 meters) above the earth, at about 200 miles (300 km.) per hour. They are narrow bands, elliptical in cross section, traveling in irregular paths. Four jet streams of interest to earth scientists and meteorologists are the polar jet stream and the subtropical jet stream in the Northern and SOUTHERN HEMISPHERES. The polar jet stream is located at the TROPOPAUSE, the BOUNDARY be-

Jet stream passing over northern Egypt and the Red Sea at a speed of about one hundred miles per hour. The Nile River can be seen on the left and the southern tip of the Sinai Peninsula at the upper right. (Corbis) tween the TROPOSPHERE and the STRATOSPHERE, along the polar FRONT. There is a complex interaction between surface winds and jet streams. In winter the NORTHERN HEMISPHERE polar front can move as far south as Texas, bringing BLIZZARDS and extreme WEATHER conditions. In summer, the polar jet stream is located over Canada. The subtropical jet stream is located at the tropopause around 30 DEGREES north or south LATITUDE, but it also migrates north or south, depending on the SEASON. At times, the polar and subtropical jet streams merge for a few DAYS. Aircraft take advantage of the jet stream, or avoid it, depending on the direction of their flight. Upper atmosphere winds are also known as GEOSTROPHIC winds.

Jetty. Structure built to protect a HARBOR entrance from WAVE EROSION or to prevent DEPOSITION.

Joint. Naturally occurring fine crack in a ROCK, formed by cooling or by other stresses. SEDIMENTARY ROCKS can split along bedding planes; other joints form at right angles to the STRATA, running vertically through the rocks. In IGNEOUS ROCKS such as GRANITE, the stresses of cooling and contraction cause three sets of joints, two vertical and one parallel to the surface, which leads to the formation of distinctive LANDFORMS such as TORS. BASALT often demonstrates columnar jointing, producing tall columns that are mostly hexagonal in section. The presence of joints in BEDROCK hastens WEATHERING, because water can penetrate into the joints. This is particularly obvious in LIMESTONE, where joints are rapidly enlarged by SOLUTION. FROST WEDGING is a type of PHYSICAL WEATHERING that can split large boulders through the expansion when water in a joint freezes to form ice. Compare with FAULTS, which occur through tectonic activity.

Frost-split granite boulder. (U.S. Geological Survey)

Jungle. Degenerate form of tropical RAIN FOREST that grows where the upper, closed-tree canopy is absent, allowing smaller trees and shrubs to flourish. In this dense, leafy VEGETATION, a machete is needed to hack a path through the luxuriant plant growth. In a true tropical rain forest, the upper closed canopy of leaves prevents sunlight from reaching the forest floor, so there is little undergrowth, and a person can walk through easily. Jungle occurs naturally along the BANKS of RIVERS or when a STORM fells trees of the forest. When an area of rain forest is cleared for subsistence farming and later abandoned, jungle is an intermediate stage in the return to true rain forest. However, POPULATION pressure in many countries means that increasing areas of tropical rain forest cannot regenerate.

Jurassic. Second of the three PERIODS that make up the MESOZOIC ERA. It occurred around 208 to 144 million years ago and lasted for around 64 million years. Dinosaurs lived on Earth during the Jurassic, including the giant vegetarians and the smaller CARNIVORES. Birds and small mammals appeared during this time; ammonites, sharks, plesiosaurs, and bony fish lived in the SEAS. The dominant plants were cycads, together with CONIFEROUS FORESTS. The name comes from the Jura Mountains of France and Switzerland.

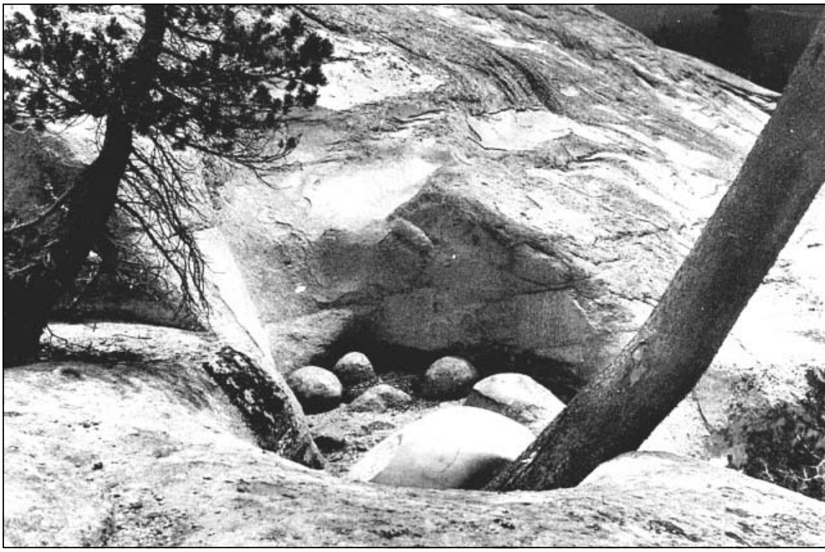
Kame. Small HILL of gravel or mixed-size deposits, SAND, and gravel. Kames are found in areas previously covered by CONTINENTAL GLACIERS or ICE SHEETS, near what was the outer edge of the ice. They may have formed by materials dropping out of the melting ice, or in a deltalike deposit by a STREAM of MELTWATER. These deposits of which kames are made are called drift. Small LAKES called KETTLES are often found nearby. A closely spaced group of kames is called a kame field.

Kames in Happy Valley in Greenland's Nunatarssuaq region. (U.S. Geological Survey)

Unusual karst formations in Utah's Goblin Valley. (Corbis)

Karst. LANDSCAPE of SINKHOLES, underground STREAMS and caverns, and associated features created by CHEMICAL WEATHERING, especially SOLUTION, in REGIONS where the BEDROCK is LIMESTONE. The name comes from a region in the southwest of what is now Slovenia, the Krs (Kras) Plateau, but the karst region extends south through the Dinaric Alps bordering the Adriatic Sea, into Bosnia-Herzegovina and Montenegro. Where limestone is well jointed, RAINFALL penetrates the JOINTS and enters the GROUNDWATER, carrying the MINERALS, especially calcium, away in solution. Most of the famous CAVES and caverns of the world are found in karst areas. The Carlsbad Caverns in New Mexico are a good example. Kentucky, Tennessee, and Florida also have well-known areas of karst. In some tropical countries, a form called tower karst is found. Tall conical or steep-sided HILLS of limestone rise above the flat surrounding landscape. Around 15 percent of the earth's land surface is karst TOPOGRAPHY.

Katabatic wind. GRAVITY DRAINAGE WINDS similar to MOUNTAIN BREEZES but stronger in force and over a larger area than a single VALLEY. Cold AIR collects over an elevated REGION, and the dense cold air flows strongly downslope. The ICESHEETS of Antarctica and Greenland produce fierce katabatic winds, but they can occur in smaller regions. The BORA is a strong, cold, squally downslope wind on the Dalmatian COAST of Yugoslavia in winter.



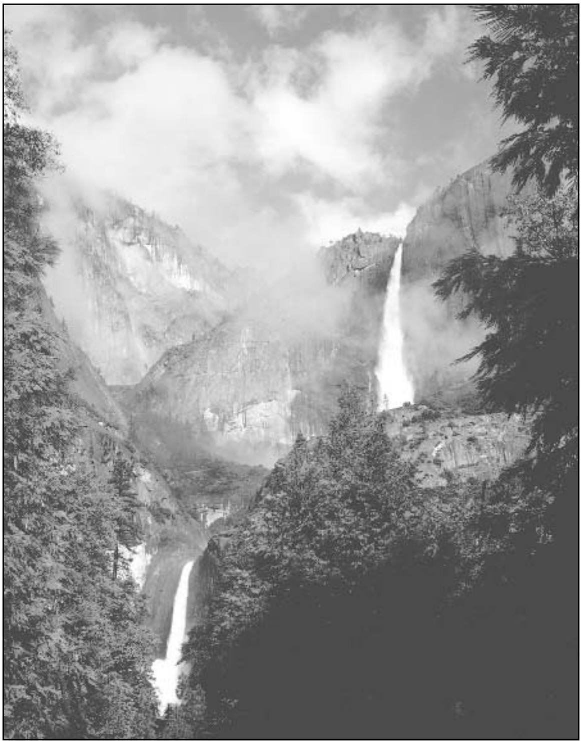
Kettle near Tuolumne Meadows in California's Yosemite National Park. (U.S. Geological Survey)

Kettle. Small depression, often a small LAKE, produced as a result of continental GLACIATION. It is formed by an isolated block of ice remaining in the ground MORAINE after a GLACIER has retreated. Deposited material accumulates around the ice, and when it finally melts, a steep hole remains, which often fills with water. Walden Pond, made famous by writer Henry David Thoreau (1817-1862), is a glacial kettle.

Key. Small coral ISLAND; a sandy island built up by WAVE action on a CORAL REEF. The Florida Keys are a good example from the United States. Called CAYS in other countries.

Khamsin. Hot, dry, DUST-laden WIND that blows in the eastern Sahara, in Egypt, and in Saudi Arabia, bringing high TEMPERATURES for three or four DAYS. Winds can reach GALE force in intensity. The word Khamsin is Arabic for "fifty" and refers to the period between March and June when the khamsin can occur.

Knickpoint. Abrupt change in gradient of the bed of a RIVER OR STREAM; sometimes spelled nickpoint. It is marked by a WATERFALL, which over time is eroded by FLUVIAL action, restoring the smooth profile of the riverbed. The knickpoint acts as a TEMPORARY BASE LEVEL for the upper part of the stream. Knickpoints can occur where a hard layer of ROCK is slower to erode than the rocks downstream, for example at Niagara Falls. Other knickpoints and waterfalls can develop as a result of tectonic forces. UPLIFT leads to new EROSION by a stream, creating a knickpoint that gradually moves upstream. The bed of a tributary GLACIER is often considerably higher than the VALLEY of the main glacier,



Yosemite Falls, the highest waterfall in Yosemite National Park, is fed by melting glacial ice at a higher altitude. (PhotoDisc)

so that after the glaciers have melted, a waterfall emerges over this knickpoint from the smaller hanging valley to join the main stream. Yosemite National Park has several such waterfalls.

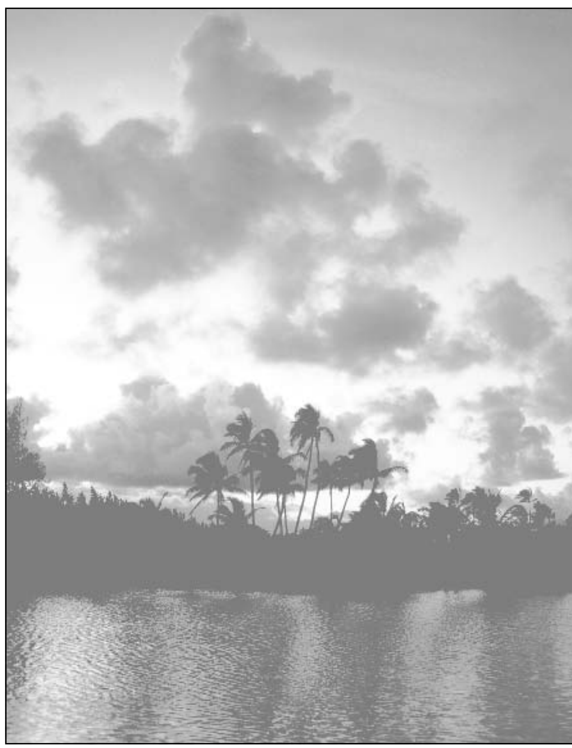
Koeppen climate classification. Commonly used scheme of CLIMATE classification that uses statistics of average monthly TEMPERATURE, average monthly PRECIPITATION, and total annual precipitation. The system was devised by Wladimir Koeppen early in the twentieth century.

Kopje. South African word for a small flat-topped LANDFORM; called a BUTTE in the United States.

La Niña. WEATHER phenomenon that is the opposite part of EL NIÑO. When the SURFACE WATER in the eastern Pacific Ocean is cooler than average, the southeast TRADE WINDS blow strongly, bringing heavy rains to countries of the western Pacific. Scientists refer to the whole RANGE of TEMPERATURE, pressure, WIND, and SEA LEVEL changes as the SOUTHERN OSCILLATION (ENSO). The term "El Niño" gained wide currency in the American media after a strong ENSO warm event in 1997-1998. A weak ENSO cold event, or La Niña, followed it in 1998. Means "the little girl" in Spanish. Alternative terms are "El Viejo" and "anti-El Niño."

Laccolith. LANDFORM of INTRUSIVE volcanism formed when viscous MAGMA is forced between overlying sedimentary STRATA, causing the surface to bulge upward in a domelike shape.

Lagoon. Area of shallow, quiet water, separated from the OCEAN by a natural barrier. There are two types of lagoons—coastal and coral. Coastal lagoons are long and narrow, separated from the SEA by a SANDBAR, with a narrow outlet to the sea. The water height in the lagoon changes with the TIDE. Over time the continued supply of SEDIMENT by STREAMS may lead to the infilling of a coastal lagoon, so that it becomes a WETLAND or SALT MARSH. A coral lagoon is found where a barrier REEF separates the land from the ocean. In the case of an ATOLL, there is no land, only the ring of coral surrounding the lagoon.



Lagoon in Kauai in the Hawaiian Islands. (PhotoDisc)

Lahar. Type of mass movement in which a MUDFLOW occurs because of a volcanic explosion or ERUPTION. The usual cause is that the heat from the LAVA or other pyroclastic material melts ice and SNOW at the VOLCANO'S SUMMIT, causing a hot mudflow that can move downslope with great speed. The eruption of Mount Saint Helens in 1985 was accompanied by a lahar.

One of the largest artificial lakes in the world, Lake Mead (pictured in 1985) was created by the construction of Hoover Dam, which traps the Colorado River, as it enters from the east (to the right), and other tributaries. Creation of the lake along the Nevada-Arizona border has helped make possible the growth of nearby Las Vegas (left) and the national recreation area that surrounds the irregularly shaped lake. (Corbis)

Lake. Large body of water enclosed in a BASIN. STREAMS enter and leave it, so there is a slow movement of water through the lake. If a lake has no outlet, its water becomes saline. There is considerable confusion over terminology because the world's largest lake is saline and is called the Caspian Sea; however, it is not a true SEA, nor is its neighbor, the Aral Sea. The world's largest freshwater lake in terms of surface area is North America's Lake Superior. The lake with the greatest volume of FRESH WATER is Lake Baikal in Siberia. There also are artificial lakes created by human activities such as DAM construction. Lake Powell on the Colorado River is a controversial example.

Lake basin. Enclosed depression on the surface of the land in which SURFACE WATERS collect; BASINS are created primarily by glacial activity and tectonic movement.

Lakebed. Floor of a LAKE.

Land breeze. Local WIND that is the opposite of a sea breeze. During the evening, when the land near the COAST cools more rapidly than the adjacent OCEAN, AIR rises above the warmer water, forming a low-pressure REGION. A BREEZE develops as air from over the land moves toward this lower pressure.

Land bridge. Piece of land connecting two CONTINENTS, which permits the MIGRATION of humans, animals, or plants from one area to another. Many former land bridges are now under water, because of the rise in SEA LEVEL after the last ICE AGE. The Bering Strait connecting Asia and North America was an important land bridge for the latter continent.

Land hemisphere. Because the DISTRIBUTION of land and water surfaces on Earth is quite asymmetrical on either side of the EQUATOR, the NORTHERN HEMISPHERE might well be called the land hemisphere. For many centuries, Europeans refused to believe that there was not an equal area of land in the SOUTHERN HEMISPHERE. Explorers such as James Cook were dispatched to seek such a "Great South Land."

Land use. Predominant activity over an area. Common land uses include AGRICULTURE, forestry, NATIONAL PARKS, and reserves. In modern times, more land is being used for URBAN residential and industrial purposes and for roads and other INFRASTRUCTURE. Often, the best agricultural land is thereby taken out of production.

Landform. Conspicuous feature on the surface or CRUST of the earth, including underwater. Landforms are also studied on other PLANETS, using vehicles such as the Mars Explorer. Common landforms include MOUNTAINS of various kinds, PLATEAUS, and VALLEYS. Landforms can be understood through a study of the processes that led to their formation. Tectonic landforms are produced through CRUSTAL MOVEMENT. Volcanic landforms result from cooling of MAGMA. Structural landforms are produced by EROSION or DEPOSITION by the forces of STREAMS, GLACIERS, WAVES, and WINDS. Biogenic landforms are produced by organisms such as coral or termites, or, more extensively, by humans. GEOMORPHOLOGY is the study of the origin and development of landforms.

Landlocked country. NATION that is surrounded by other countries and does not have an OCEAN COAST. This is an economic disadvantage in terms of PORT facilities and international TRADE, since exports and imports must pass through a neighboring COUNTRY. A landlocked country also has no control of the fishing and OIL RESOURCES of the CONTINENTAL SHELF or an exclusive economic zone, both of which are enjoyed by countries with a COASTLINE. Bolivia and Paraguay are landlocked countries in South America. Many countries in Asia, Europe, and Africa are landlocked.

Landmass. Large area of land—an ISLAND or a CONTINENT.

Landsat. Space-exploration project begun in 1972 to MAP the earth continuously with SATELLITE imaging. The satellites have collected data about the earth: its AGRICULTURE, FORESTS, flat lands, MINERALS, waters, and ENVIRONMENT. These were the first satellites to aid in Earth sciences, helping to produce the best maps available and assisting farmers around the world to improve their crop yields.

Landscape. Natural landscape is made up of LANDFORMS that reflect the processes operating in the area for greater or shorter periods of time. A KARST landscape, for example, consists of distinctive landforms such as SINKHOLES, UVALA, DOLINES, and caverns. A glacial landscape shows the results of EROSION or DEPOSITION by ice. Most landscapes are shaped by FLUVIAL processes, or STREAMS and running water.

Landslide. Sudden, rapid downslope movement of earth or ROCK, although the latter is also called a rockslide; one of the forms of mass movement. In a landslide, a section of the hillside moves as a cohesive mass along a plane parallel to the slope angle. Landslides can be caused by undercutting at the base, for example in road construction or in excavation to create a building SITE. A landslide that has a rotational component to its movement is called a SLUMP. The explosion of Mount Saint Helens involved a huge landslide triggered by an EARTHQUAKE prior to the explosion.

Language. Means of human communication. It is estimated that there are more than six thousand languages in use in the world today. Some exist only as spoken languages, but most have a written form, using symbols to record the language. There are also extinct languages that exist only as written records, such as Ancient Egyptian hieroglyphics, although some extinct languages are used for religious purposes, such as Sanskrit in Buddhism. Linguists place English in the Indo-European LANGUAGE FAMILY.

Language branch. Collection of related LANGUAGES that have developed from a common ancestor but have experienced changes over time, leading to variations in language. English belongs to the Germanic language branch of the Indo-European LANGUAGE FAMILY. Other languages in the Germanic language branch include Dutch, Swedish, Danish, Norwegian, and Icelandic. Another language branch of the Indo-European family is the Romance branch, which includes the French, Spanish, Portuguese, Italian, and Romanian languages.

Language family. Group of related LANGUAGES believed to have originated from a common prehistoric language. English belongs in the Indo-European language family, which includes the languages spoken by half of the world's peoples.

Lapilli. Small ROCK fragments that are ejected during volcanic ERUPTIONS. A lapillus ranges from about the size of a pea to not larger than a walnut. Some lapilli form by accretion of VOLCANIC ASH around moisture droplets, in a manner similar to hailstone formation. Lapilli sometimes form into a textured rock called lapillistone.

Late Precambrian era. That part of geologic time from about 550 million years to 1 billion years before the present.

Laterite. Bright red CLAY SOIL, rich in iron oxide, that forms in tropical CLIMATES, where both TEMPERATURE and PRECIPITATION are high year-round, as ROCKS weather. It can be used in brick making and is a source of iron. When the soil is rich in aluminum, it is called BAUXITE. When laterite or bauxite forms a hard layer at the surface, it is called duricrust. Australia and sub-Saharan Africa have large areas of duricrust, some of which is thought to have formed under previous conditions during the TRIASSIC period.

Latin America. WESTERN HEMISPHERE REGION generally regarded as including Mexico, Central America, most of the islands of the Caribbean, and the entire continent of South America. After the voyages of Christopher Columbus, the peoples of Latin America were conquered and colonized by the Spaniards and Portuguese, starting in the late fifteenth century.

Latitude. Measure of distance north or south on the earth's surface. Lines of latitude (also called PARALLELS) are imaginary lines running east-west around the globe. They are numbered from zero DEGREES at the EQUATOR to ninety degrees north or south at the North or South Pole, respectively. Each degree of latitude, measured along a MERIDIAN, is about 69 miles (111 km.) in length. The distance varies slightly because of the flattening of the earth towards the POLES. Lines of latitude decrease in length from 24,902 miles (40,075 km.) at the equator to a single point at the poles. The most important lines of latitude are the equator, at 0 degrees; tropic of CANCER, 23.5 degrees north; Arctic Circle, 66.5 degrees north; North Pole, 90 degrees north; tropic of CAPRICORN, 23.5 degrees south, Antarctic Circle, 66.5 degrees south; and South Pole, 90 degrees south. The equator is the only line of latitude that is a GREAT CIRCLE.

Laurasia. Hypothetical SUPERCONTINENT made up of approximately the present CONTINENTS of the NORTHERN HEMISPHERE.

Lava. MAGMA, or molten material from within the earth, that emerges at

Lava flow in Hawaii. (PhotoDisc)

the surface. It forms EXTRUSIVE IGNEOUS ROCKS such as BASALT and obsidian. The Hawaiians distinguish between two types of lava: Pahoehoe is smooth, fluid, flowing lava that hardens into ripples and folds; AA is rough, broken, jagged pieces of rock.

Lava tube. Cavern structure formed by the draining out of liquid LAVA in a pahoehoe flow.

Layered plains. Smooth, flat REGIONS believed to be composed of materials other than sulfur compounds.

Leaching. Removal of nutrients from the upper horizon or layer of a SOIL, especially in the humid TROPICS, because of heavy RAINFALL. The remaining soil is often bright red in color because iron is left behind. Despite their bright color, tropical soils are infertile.

Leeward. Rear or protected side of a MOUNTAIN or RANGE is the leeward side. Compare to WINDWARD.

Legend. Explanation of the different colors and symbols used on a MAP. For example, a map of the world might use different colors for high-income, middle-income, and low-income economies. A historical map might use different colors for countries that were once colonies of Britain, France, or Spain.

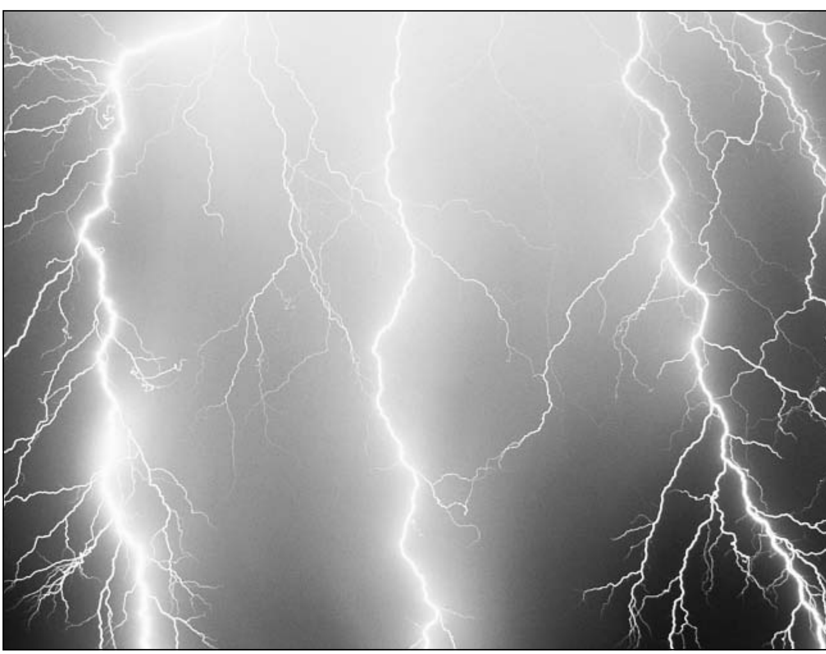
Legumes. Type of plant in which the fruit is released by the splitting open of the fruit along two sides or seams. Legumes important to humans include peas, clover, alfalfa, beans of many kinds, and peanuts. High in protein, legumes are an important part of the human food supply. Bacteria that live in the roots of most legume crops fix nitrogen in the SOIL, so legumes are grown as part of CROP ROTATION, in order to restore soil fertility naturally, without the addition of FERTILIZERS.

Levee. NATURAL LEVEES are long, low RIDGES of ALLUVIUM formed at the RIVER BANK of STREAMS flowing on FLOODPLAINS. After the stream overflows onto the floodplain annually, the water velocity decreases sharply; material deposited there forms the levee. Behind levees are low-lying areas called backswamps. Humans have built artificial levees of earth, ROCK, or concrete to try to prevent water spreading onto the floodplain. The Mississippi River has the world's largest system of artificial levees. Rivers that transport large amounts of SEDIMENT generally deposit some of it in their bed during low flow, so over time the bed of the stream becomes higher than the surrounding floodplain. This leads to catastrophic flooding when a levee is breached. Both the Mississippi and the Huang He (Yellow), in China, are good examples of this happening.

Life expectancy. Average number of years that a newly born human can expect to live in any given society or COUNTRY. In the 1990's, life expectancy in high-income economies was more than seventy years, but in many low-income economies, especially in Africa, it was less than fifty years. Women had a life expectancy a few years higher than men in all countries.

Light year. Distance traveled by light in one year; widely used for measuring stellar distances, it is equal to roughly 6 trillion miles (9.5 million km.).

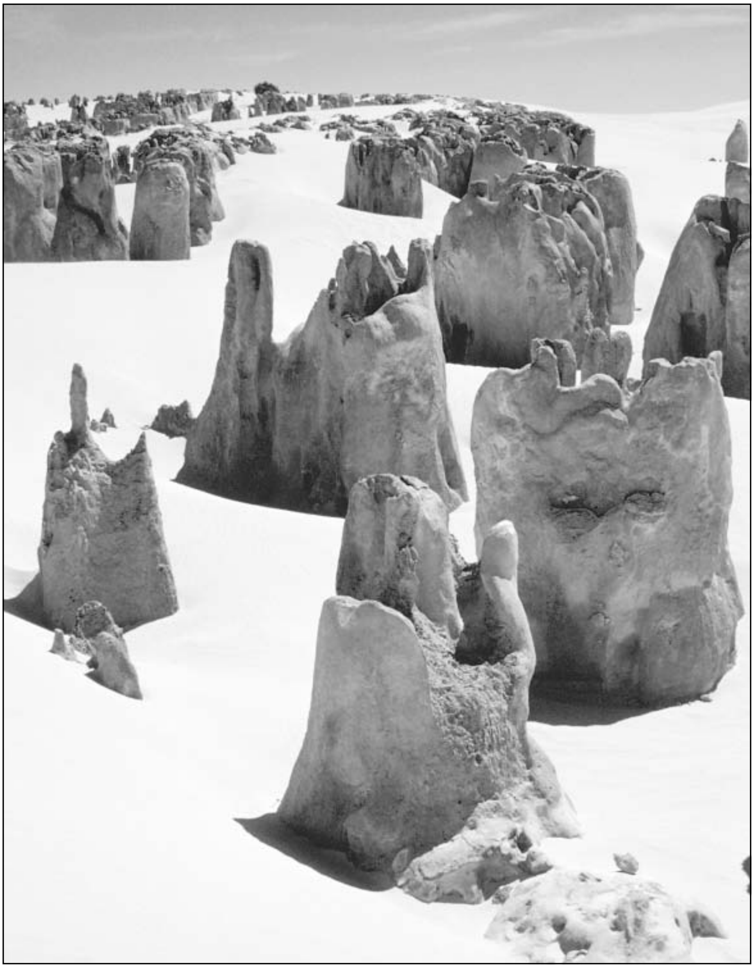
Lightning. Visible discharge of electric ENERGY in the earth's ATMOSPHERE; a giant electric arc passing from the CLOUD to the ground. Usually part of the activity associated with the growth of a CUMULONIMBUS cloud or thunderhead. A positive charge builds in the upper part of the cloud and a negative charge in the lower part. A flash of cloud-to-ground lightning involves a smaller leader stroke, followed by a brilliant return stroke. Eight million lightning strikes can occur each DAY on Earth. A lightning flash involves hundreds of millions of volts, and associated TEMPERATURES are as high as 54,000 DEGREES Fahrenheit (30,000 degrees Celsius). The heated AIR moving at supersonic speed causes the thunder that accompanies lightning. Metallic lightning rods attached to buildings attract lightning strikes and conduct the charge harmlessly to the ground.



Lightning storm. (PhotoDisc)

Lignite. Low-grade COAL, often called brown coal. It is mined and used extensively in eastern Germany, Slovakia, and the Moscow Basin.

Limestone. SEDIMENTARY ROCK comprising mainly calcium carbonate. Limestone is rich in FOSSIL remains, and their study has contributed



Some of the most unusual limestone formations in the world are found in Western Australia's Pinnacles Desert, in Nambung National Park. The limestone in these pillars—some of which are as much as ten feet tall—originated in ancient marine sea shell material brought ashore by waves and carried inland by wind. (Corbis)

greatly to our knowledge of Earth history. Distinctive LANDFORMS known as KARST are produced in areas of limestone.

Lingua franca. Latin for "language of the Franks," a mixed LANGUAGE used in the Roman Empire for TRADE. In modern usage, a widely understood and commonly spoken second language for many people. Globalization is leading to English becoming a lingua franca almost everywhere.

Liquefaction. Loss in cohesiveness of water-saturated SOIL as a result of ground shaking caused by an EARTHQUAKE.

Literacy rate. DEMOGRAPHIC MEASURE of what percentage of the adult POPULATION of a COUNTRY or REGION can read and write. Low-income countries have low literacy rates; less than 40 percent of adults are literate in countries such as Pakistan and Ethiopia, for example. Additionally, in such countries the literacy rate for women is considerably lower, as men are given access to education in greater numbers. In high-income countries, the literacy rate approaches 100 percent.

Lithic. Having to do with ROCK.

Lithification. Process whereby loose material is transformed into solid ROCK by compaction or cementation.

Lithology. Description of ROCKS, such as rock type, MINERAL makeup, and fluid in rock pores.

Lithosphere. Solid outermost layer of the earth. It varies in thickness from a few miles to more than 120 miles (200 km.). It is broken into pieces known as TECTONIC PLATES, some of which are extremely large, while others are quite small. The upper layer of the lithosphere is the CRUST, which may be CONTINENTAL CRUST or OCEANIC CRUST. Below the crust is a layer called the ASTHENOSPHERE, which is weaker and plastic, enabling the motion of tectonic plates.

Lithospheric crust. Relatively thin outer portion of Earth's "onion" structure, composed of solid ROCK.

Lithospheric plate. One of a number of crustal PLATES of various sizes that compose the earth's outer CRUST; their BORDERS are outlined by major zones of EARTHQUAKE activity.

Littoral. Adjacent to or related to a SEA.

Littoral current. See LONGSHORE CURRENT.

Livestock. Domesticated animals raised on farms or in agricultural communities for food. The term is usually applied to mammals such as sheep, pigs, cattle, and horses.

Llanos. Grassy REGION in the Orinoco Basin of Venezuela and part of Colombia. SAVANNA VEGETATION gradually gives way to scrub at the outer edges of the *llanos.* The area is relatively undeveloped.

Loam. SOIL TEXTURE classification, indicating a soil that is approximately equal parts of SAND, SILT, and CLAY. Farmers generally consider a sandy loam to be the best soil texture because of its water-retaining qualities and the ease with which it can be cultivated.

Local sea-level change. Change in SEA LEVEL only in one area of the world, usually by land rising or sinking in that specific area.

Local winds. WINDS that, over a small area, differ from the general pressure pattern owing to local thermal or orographic effects.

Location. Geographers identify two kinds of location—absolute and relative. ABSOLUTE LOCATION is a position given with coordinates of the geographic GRID, such as 33 DEGREES north and 118 degrees west. There is one precise spot on Earth corresponding to that absolute location. RELATIVE LOCATION is a verbal description of a PLACE with reference to some other place, for example, the "Middle East," the "Midwest," "Dixie."

Loch. Scottish term for a LAKE. Many lochs are products of EROSION by continental GLACIATION, and have narrow, elongated shapes. Scottish lochs are located in the Great Glen, which extends across the COUNTRY for almost 60 miles (100 km.), from Moray Firth to Loch Linnhe. The lakes are connected by the Caledonian Canal, built in the early nineteenth century by Thomas Telford. Loch Ness, in northern Scotland, is the largest freshwater lake in Great Britain. Loch Lomond, another large Scottish lake, located near Glasgow, is the subject of a well-known Scottish song.

Lode deposit. Primary deposit, generally a VEIN, formed by the filling of a FISSURE with MINERALS precipitated from a HYDROTHERMAL solution.

Loess. EOLIAN, or wind-blown, deposit of fine, silt-sized, light-colored material. Loess covers about 10 percent of the earth's land surface. The loess PLATEAU of China is good agricultural land, although susceptible to EROSION. Loess has the property of being able to form vertical CLIFFS or BLUFFS, and many people have built dwellings in the steep cliffs above the Huang He (Yellow) River. In the United States, loess deposits are found in the VALLEYS of the Platte, Missouri, Mississippi, and Ohio Rivers, and on the Columbian Plateau. A German word, meaning loose or unconsolidated, which comes from loess deposits along the Rhine River.

Longitude. Measure of angular distance on the earth's surface, east or west of the PRIME MERIDIAN. Lines of longitude (called MERIDIANS) are imaginary lines, numbered from 0 DEGREES at the prime meridian through 180 degrees, either east or west. They converge at the North and South Poles. One degree of longitude is 69 miles (111 km.) at the EQUATOR, but less than half of that distance at 60 degrees north or south LATITUDE, reducing to zero at the POLES. Each meridian is half of a GREAT CIRCLE.

Longitudinal bar. Midchannel accumulation of SAND and gravel with its long end oriented roughly parallel to the RIVER flow.

Longitudinal dune. Elongate SAND DUNE parallel to the prevailing WIND.

Longshore current. Current in the OCEAN close to the SHORE, in the surf zone, produced by WAVES approaching the COAST at an angle. Also called a LITTORAL current. The longshore current combined with wave action can move large amounts of SAND and other BEACH materials down the coast, a process called LONGSHORE DRIFT.

Longshore drift. The movement of SEDIMENT parallel to the BEACH by a LONGSHORE CURRENT.

Low island. ISLAND made of coral and coral SAND, especially common in the Pacific Ocean. Because these islands have low ELEVATION, they receive no OROGRAPHIC PRECIPITATION and AGRICULTURE is not possible. Therefore, low islands can support only small POPULATIONS. They are in danger of inundation as GLOBAL WARMING leads to a rise in SEA LEVEL.

Low velocity zone. See ASTHENOSPHERE.

Lunar eclipse. See ECLIPSE, LUNAR.

Maar. Explosion vent at the earth's surface where a volcanic cone has not formed. A small ring of pyroclastic materials surrounds the maar. Often a LAKE occupies the small CRATER of a maar. A larger form is called a TUFF RING.

Macroburst. Updrafts and downdrafts within a CUMULONIMBUS CLOUD or THUNDERSTORM can cause severe TURBULENCE. A DOWNBURST within a thunderstorm when windspeeds are greater than 130 miles (210 km.) per hour and over areas of 2.5 square miles (5 sq. km.) or more is called a macroburst. See also MICROBURST.

Macrofossil. FOSSIL large enough to study with the unaided eye, as opposed to a microfossil, which requires a microscope for examination.

Magma. Body of molten ROCK, including any dissolved gases and suspended crystals.

Magnetic declination. See DECLINATION, MAGNETIC.

Magnetic field. Magnetic lines of force that are projected from the earth's interior and out into space.

Magnetic poles. Locations on the earth's surface where the earth's MAGNETIC FIELD is perpendicular to the surface. The magnetic poles do not correspond exactly to the geographic North Pole and South Pole, or earth's AXIS; the difference is called magnetic variation or DECLINATION.

Magnetic reversal. Change in the earth's MAGNETIC FIELD from the North Pole to the South MAGNETIC POLE.

Magnetic storm. Rapid changes in the earth's MAGNETIC FIELD as a result of the bombardment of the earth by electrically charged particles from the SUN.

Magnetic survey. MEASUREMENTS of the magnetic elements at many points, on or above the earth's surface, carried out by field teams, airborne magnetometers, ships at SEA, or SATELLITES.

Magnetism. The MAGNETIC FIELD of Earth is like a bar magnet, with one end being the North Pole and the opposite end the South Pole. The MAGNETOSPHERE extends on average more than one hundred miles above the earth's surface. The principal source of the magnetism is the movement of the liquid OUTER CORE, which is heated by radioactive decay of the INNER CORE. The use of a magnet COMPASS for NAVIGATION was known in ancient times. Earth's magnetic field has reversed its POLARITY many times; studies of PALEOMAGNETISM at the mid-Atlantic Ridge were an important contribution to the development of the modern theory of PLATE TECTONICS. Magnetic currents extend into the ATMOSPHERE, protecting the earth from the SOLAR WIND, and also causing effects known as AURORAS.

Magnetosphere. REGION surrounding a PLANET where the planet's own MAGNETIC FIELD predominates over magnetic influences from the SUN or other planets.

Mandate. Term applied by the League of Nations to the German colonies it assigned to the administration of Great Britain, France, and South

Africa after World War I. After the United Nations succeeded the League of Nations in the 1940's, the mandate territories were officially redesignated trust territories.

Mangrove swamp. WETLAND, similar to a midlatitude SWAMP. Along low-lying COASTS in the TROPICS, and in some subtropical areas, coasts are forested in low halophytic trees called mangroves. These mangroves, and some associated plants, grow in tidal LAGOONS and estuaries in muddy, anaerobic conditions. Despite their impenetrable nature and their odiferous qualities, mangrove swamps form a highly productive ECOSYSTEM.

Mantle. Part of the earth below the CRUST, surrounding the CORE. The separation between the crust and the mantle is called the Mohorovičić discontinuity, shortened often to the "Moho." The mantle is approximately 1,800 miles (2,900 km.) thick, comprising more than 80 percent of Earth's volume but only two-thirds of its weight, since the core is much denser. Geophysicists differentiate between the UPPER MANTLE (about 600 miles/1,000 km. thick) and the lower mantle. The uppermost part of the mantle is the ASTHENOSPHERE.

Mantle convection. Thermally driven flow in the earth's MANTLE thought to be the driving force of PLATE TECTONICS.

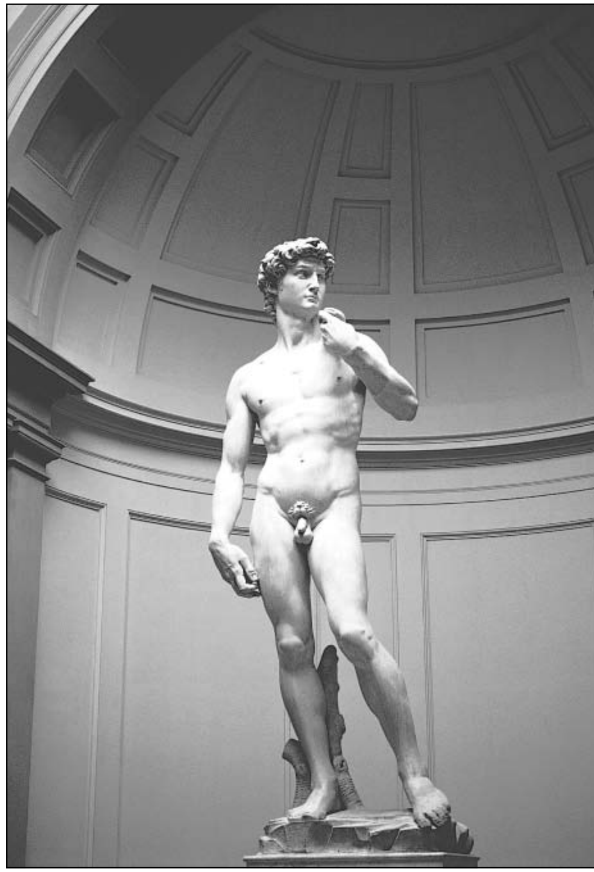
Mantle plume. Rising jet of hot MANTLE material that produces tremendous volumes of basaltic LAVA. See also HOT SPOT.

Map. Representation of all or part of the earth's surface at a smaller size. A globe is the only accurate map of Earth, since transformation of a three-dimensional body to a two-dimensional surface such as a sheet of paper involves distortions of shape, size, and direction. A map used for NAVIGATION is referred to as a CHART. A map used for determining and recording property boundaries is a PLAT. The art and science of map-making is CARTOGRAPHY. See also AZIMUTHAL PROJECTION; CONICAL PROJECTION; CYLINDRICAL PROJECTION.

Map projection. Mathematical formula used to transform the curved surface of the earth onto a flat plane or sheet of paper. Projections are divided into three classes: CYLINDRICAL, CONICAL, and AZIMUTHAL.

Maquiladora. Term for modern factories and industrial establishments in Mexico, where foreign components are assembled into products for export, especially to the United States. Maquiladoras are usually owned by American or Japanese transnational companies and are usually located near the U.S. BORDER. Mexico benefits through increased employment and worker training; the creation of the North American Free Trade Agreement (NAFTA) meant a reduction of import duties, making the goods cheaper to American purchasers. Cities on the U.S.-Mexico border are economically favorable locations for maquiladoras, and Tijuana and Ciudad Juarez are the two largest.

Marble. LIMESTONE that has been crystallized by heat and pressure. The process of recrystallization destroys FOSSILS as they change into calcite.



The Renaissance artist Michelangelo carved his famous statue David *from white marble in the early sixteenth century. The statue now stands in Florence, Italy.* (PhotoDisc)

Marble comes in many colors, but sculptors such as Michelangelo historically preferred the pure white marble found at Cararra in Italy.

Marchland. FRONTIER area where boundaries are poorly defined or absent. The marches themselves were a type of BOUNDARY REGION. Marchlands have changed hands frequently throughout history. The name is related to the fact that armies marched across them.

Marine. Pertaining to a seawater, OCEAN ENVIRONMENT.

Market town. Small TOWN OR VILLAGE that holds regular public markets. Historically, market towns were gathering points in larger areas.

Marl. Type of CLASTIC ROCK that is a naturally occurring mixture of CLAY and LIMESTONE. The fine-grained calcareous material can originate under freshwater conditions, in LAKES, or under MARINE conditions. Used in the manufacture of cement and in brickmaking.

Marsh. WETLAND whose dominant VEGETATION is grass. Marshes generally occur in the middle LATITUDES at the MOUTHS OF RIVERS, in estuaries and LAGOONS, and especially if there is a DELTA. Saltwater marshes

Typical marshland. (PhotoDisc)

are covered in a thick mat of sedges and similar plants and periodically are flooded by TIDES. Low ELEVATION and poor DRAINAGE provide marsh conditions where highly productive ECOSYSTEMS develop. Similar wetlands with tree vegetation are called SWAMPS. The Florida Everglades are a combination of marsh and swamp. Other small freshwater marsh areas are found in REGIONS previously covered by CONTINENTAL GLACIERS. On tropical COASTS, the wetlands are MANGROVE SWAMPS.

Mass balance. Summation of the net gain and loss of ice and SNOW mass on a GLACIER in a year.

Mass extinction. Die-off of a large percentage of species in a short time.

Mass wasting. Downslope movement of Earth materials under the direct influence of GRAVITY.

Massif. French term used in geology to describe very large, usually IGNEOUS INTRUSIVE bodies.

Material culture. Visible and tangible products or objects made and used by a particular group; includes clothing, weapons, household items, tools, and buildings.

Mean sea level. Average height of the SEA surface over a multiyear time span, taking into account STORMS, TIDES, and SEASONS.

Meander. U-shaped bend in a RIVER. MEANDERING RIVERS generally flow across a FLOODPLAIN that has been built up of ALLUVIUM deposited by the STREAM. An extremely tight meander is called a gooseneck; it is likely to become a cutoff, or OXBOW LAKE, after a FLOOD. Tectonic UPLIFT can cause a river to continue downcutting along its meandering course, producing incised or entrenched meanders. The word comes from the winding, meandering river in Turkey that the Romans called Menderes.

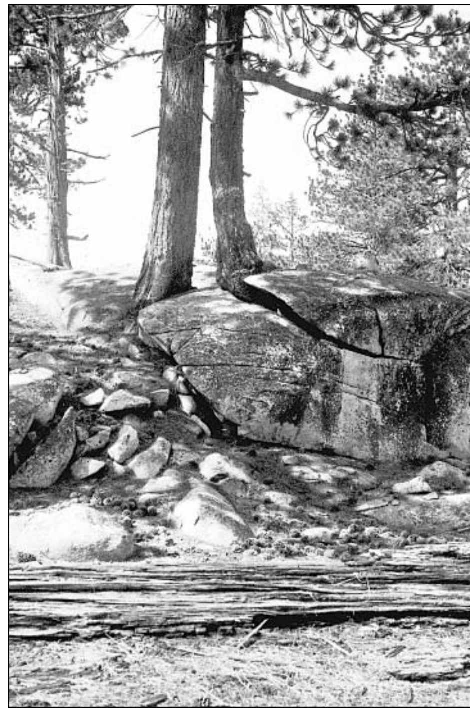
Meandering river. RIVER confined essentially to a single CHANNEL that transports much of its SEDIMENT load as fine-grained material in SUSPENSION.

A meandering river. (PhotoDisc)

Measurement, systems of. The imperial system of measurement used in the United States was brought by the British in the seventeenth century. Distances are measured in miles, feet, or inches; weights in tons, pounds, and ounces; volume in gallons, quarts, and pints. In most countries of the world, measurements are made in the International System of Units, or metric system. This system, which uses decimal fractions or units of ten, developed after the French Revolution. The unit of distance, the meter, was defined as one-ten-millionth of the length of the MERIDIAN passing through Paris. The unit of weight, the gram, was defined as the weight of one cubic centimeter of water at 39 DEGREES Fahrenheit (4 degrees Celsius). A liter was defined as the volume of a cube with a side of 10 centimeters. The standards were revised and expanded, starting in 1960, so that 1 meter is now defined, in the International System, as the distance traveled by light in a vacuum in 1/299,792,458 second.

Mechanical weathering. Another name for PHYSICAL WEATHERING, or the breaking down of ROCK into smaller pieces.

Mechanization. Replacement of human labor with machines. Mechanization occurred in AGRICULTURE as tractors, reapers, picking machinery, and similar technological inventions took the place of human farm labor. Mechanization in industry was part of the INDUSTRIAL REVOLUTION, as spinning and weaving machines were introduced into the textile industry.



Example of mechanical weathering and rock uplifted by tree roots. (U.S. Geological Survey)

Medical geography. Branch of geography specializing in the study of health and disease, with a particular emphasis on the areal spread or DIFFUSION of disease. The spatial perspective of geography can lead to new medical insights. Geographers working with medical researchers in Africa have made great contributions to understanding the role of disease on that CONTINENT. John Snow's studies of the origin and spread of cholera in London in 1854 mark the beginnings of medical geography.

Mediterranean climate. Midlatitude CLIMATE characterized by wet winters and long dry summers. The climate predominates around the Mediterranean Sea, as well as in small parts of other CONTINENTS, including California, central Chile, the southernmost part of South Africa, and the southwest corner of Australia. These are all west COASTS of continents.

Megacity. Term for the world's largest URBAN AREAS, generally a conurbation with a POPULATION of more than five million. METROPOLIS is an alternative term.

Megalopolis. Conurbation formed when large cities coalesce physically into one huge built-up area. Originally coined by the French geographer Jean Gottman in the early 1960's for the northeastern part of the United States, from Boston to Washington, D.C.

Meltwater. Water derived from the melting of GLACIER ice.

Mental map. Each person's conception of the world. Persons organize space according to their mental maps. They know how to get to school or work, or a movie theater, for example, without having to look at a MAP. They may be able to cross a CITY using a mental map of major streets or highways, without actually knowing the details of the spaces traversed.

Mercalli scale. Qualitative SCALE used to describe EARTHQUAKE intensity before the creation of the RICHTER SCALE. The violence of SEISMIC shaking is given a number based on a description of the effects. The Mercalli scale uses Roman numerals I through XII for earthquakes ranging from "detected only by SEISMOGRAPHS" to "catastrophic."

Mercator projection. See CYLINDRICAL PROJECTION.

Meridian. Line of LONGITUDE.

Mesas in the Grand Canyon. (PhotoDisc)

Mesa. Flat-topped HILL with steep sides. EROSION removes the surrounding materials, while the mesa is protected by a cap of harder, more resistant ROCK. Usually found in arid REGIONS. A larger LANDFORM of this type is a PLATEAU; a smaller feature is a BUTTE. The Colorado Plateau and Grand Canyon in particular are rich in these landforms. From the Spanish word for table.

Mesosphere. Atmospheric layer above the STRATOSPHERE where TEMPERATURE drops rapidly.

Mesozoic era. Middle of the three ERAS that constitute the PHANEROZOIC EON (the last 544 million years), which encompasses three geologic PERIODS—the TRIASSIC, the JURASSIC, and the CRETACEOUS—and represents Earth history between about 250 and 65 million years ago.

Mestizo. Person of mixed European and Amerindian ancestry, especially in countries of LATIN AMERICA.

Metamorphic rock. Any ROCK whose mineralogy, MINERAL chemistry, or TEXTURE has been altered by heat, pressure, or changes in composition; metamorphic rocks may have IGNEOUS, SEDIMENTARY, or other, older metamorphic rocks as their precursors.

Metamorphic zone. Areas of ROCK affected by the same limited RANGE of TEMPERATURE and pressure conditions, commonly identified by the presence of a key individual MINERAL or group of minerals.

Metamorphism. Alteration of the mineralogy and TEXTURE of ROCKS because of changes in pressure and TEMPERATURE conditions or chemically active fluids.

Meteor. METEOROID that enters the ATMOSPHERE of a PLANET and is destroyed through frictional heating as it comes in contact with the various gases present in the atmosphere.

Meteor shower. Annual passage of Earth through a cometary wake or debris field, causing a METEOR display as COMET dust particles burn up in the upper ATMOSPHERE.

Meteoric water. Water that originally came from the ATMOSPHERE, perhaps in the form of rain or SNOW, as contrasted with water that has escaped from MAGMA.

Meteorite. Fragment of an ASTEROID that survives passage through the ATMOSPHERE and strikes the surface of the earth.

Meteoroid. Small planetary body that enters Earth's ATMOSPHERE because its path intersects the earth's ORBIT. Friction caused by the earth's atmosphere on the meteoroid creates a glowing METEOR, or "shooting star." This is a common phenomenon, and most meteors burn away completely. Those that are large enough to reach the ground are called METEORITES.

Meteorology. Study of short-term variations in the earth's ATMOSPHERE, particularly in the TROPOSPHERE. DAY-to-day changes in TEMPERATURE, HUMIDITY, PRECIPITATION, and pressure form the basis for meteorology. WEATHER forecasters use meteorological techniques. In contrast, CLIMATOLOGY is the description and analysis of CLIMATE, based on the study of long-term behavior of atmospheric variables.

Metropolis. Large CITY with its suburbs. From the Greek word for "mother city."

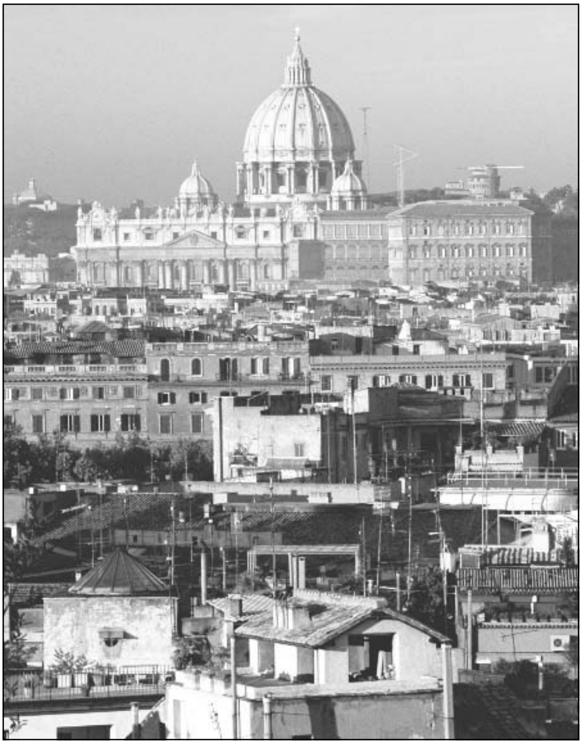
Metropolitan area. In general terms, a central CITY and the contiguous built-up area, together with the surrounding nonurban area that is economically tied to the central city. For statistical and CENSUS purposes, there exist formal definitions of a metropolitan area, which have been changed over time. In the year 2000, the U.S. Office of Management and Budget defined a metropolitan area (MA) as a CORE REGION containing a large POPULATION nucleus, together with adjacent communities having a high degree of economic and social integration with that core. MAs include metropolitan statistical areas (MSAs), consolidated metropolitan statistical areas (CMSAs), and primary metropolitan statistical areas (PMSAs). An MSA was defined as one city with 50,000 or more inhabitants, or a Census Bureau-defined urbanized area (of at least 50,000 inhabitants) and a total metropolitan population of at least 100,000 (75,000 in New England). An area that meets these requirements for recognition as an MSA and also has a population of one million or more may be recognized as a CMSA if separate component areas can be identified within the entire area by meeting statistical criteria specified in the standards, and local opinion indicates there is support for the component areas. If recognized, the component areas are designated PMSAs, and the entire area becomes a CMSA. PMSAs, like the CMSAs that contain them, are composed of entire counties, except in New England, where they are composed of cities and TOWNS. If no PMSAs are recognized, the entire area is designated as an MSA. In June, 1999, there were 258 MSAs, and 18 CMSAs comprising 73 PMSAs in the United States. In addition, there were 3 MSAs, 1 CMSA, and 3 PMSAs in Puerto Rico.

Microburst. Brief but intense downward WIND, lasting not more than fifteen minutes over an area of 0.6 to 0.9 square mile (1.5-8 sq. km.). Usually associated with THUNDERSTORMS, but are quite unpredictable. The sudden change in wind direction associated with a microburst can create wind shear that causes airplanes to crash, especially if it occurs during takeoff or landing. See also MACROBURST.

Microclimate. CLIMATE of a small area, at or within a few yards of the earth's surface. In this REGION, variations of TEMPERATURE, PRECIPITATION, and moisture can have a pronounced effect on the bioclimate, influencing the growth or well-being of plants and animals, including humans. DEW OR FROST, RAIN SHADOW effects, wind-tunneling between tall buildings, and similar phenomena are studied by microclimatologists. Horticulturists know the variations in aspect that affect INSOLATION and temperature, so that certain plants grow best on south-facing walls, for example. The growing of grapes for wine production is a major industry where microclimatology is essential. The study of microclimatology was pioneered by the German meteorologist Rudolf Geiger.

Microcontinent. Independent LITHOSPHERIC PLATE that is smaller than a CONTINENT but possesses continental-type CRUST. Examples include Cuba and Japan.

Microstates. Tiny countries. In 2000, seventeen independent countries each had an area of less than 200 square miles (520 sq. km.). The



A true microstate, Vatican City is an independent country that occupies less than a fifth of a square mile within the Italian city of Rome. (PhotoDisc)

smallest microstate is Vatican City, with an area of 0.2 square miles (0.5 sq. km.). The tiny PRINCIPALITY of Monaco has an area of 1.0 square miles (1.95 sq. km.). Other European microstates include San Marino, Liechtenstein, and Andorra. Most of the world's microstates are island NATIONS, including Nauru, Tuvalu, Marshall Islands, Saint Kitts and Nevis, Seychelles, Maldives, Malta, Grenada, Saint Vincent and the Grenadines, Barbados, Antigua and Barbuda, and Palau.

Middle atmosphere. General term encompassing the STRATOSPHERE and the MESOSPHERE.

Mid-ocean ridge. Continuous mountain RANGE of underwater VOLCANOES located along the center of most OCEAN BASINS; volcanic ERUPTIONS along these RIDGES drive SEAFLOOR SPREADING.

Migration. Change in PLACE of residence. Human migration used to be regarded as implying the intention of permanent residence at the destination, but this idea is breaking down as a result of modern transport. Migration is usually VOLUNTARY, and most twentieth century immigrants moved from low-income countries to high-income countries as economic immigrants. Migration can be FORCED, as in the case of political refugees fleeing repressive governments. These are examples of INTERNATIONAL MIGRATION. Demographers also study INTERNAL

MIGRATION, within a single COUNTRY, such as the SUN BELT migration in the United States.

Mineral. Substance that occurs naturally and has a unique chemical composition and a distinct crystal structure. Most minerals occur in compounds, but some metallic minerals occur as elements, such as copper and gold. ROCKS are composed of combinations of various minerals. The most common minerals on Earth are silicates.

Copper ore in its native state. (U.S. Geological Survey)

Mineral species. Mineralogic division in which all the varieties in any one species have the same basic physical and chemical properties.

Mineral variety. Division of a MINERAL SPECIES based upon color, type of optical phenomenon, or other distinguishing characteristics of appearance.

Miocene epoch. Geological EPOCH of the TERTIARY PERIOD in the CENOZOIC ERA, beginning about 26 million years ago.

Mist. Tiny water droplets—having a diameter of less than two hundred microns—held suspended in AIR. Visibility is impaired by the thin gray mist but remains above 0.6 mile (1 km.). When visibility is less than 0.6 mile, the condition is called FOG. A cold dense combination of fog and

Sunset mist in Florida. (Visit Florida)

rain DRIZZLE, often encountered in Scotland and similar cold CLIMATE REGIONS, is called scotch mist.

Model. Scientific term for a hypothetical description of an idea or phenomenon that explains its characteristics in a way that makes the model useful for further study of its characteristics. Examples in this glossary include CYCLE OF EROSION and DEMOGRAPHIC TRANSITION.

Monadnock. Isolated HILL far from a STREAM, composed of resistant BEDROCK. Monadnocks are found in humid temperate REGIONS. A similar LANDFORM in an arid region is an INSELBERG.

Monarchy. System or rule by a single person or sovereign ruler. The position is hereditary, as opposed to REPUBLICS, where the head of STATE is elected. Monarchs used to claim that they were appointed by God; this is referred to as the Divine Right of Kings. The Japanese held the concept of imperial divinity until 1945. As NATION-STATES evolved in Europe, some new monarchs were absolute rulers. In contrast, the power of the monarch in England was limited by the Parliament. Many modern monarchs have largely ceremonial roles.

Monogenetic. Pertaining to a volcanic ERUPTION in which a single vent is used only once.

Monsoon. Seasonal reversal of WIND. The largest monsoonal phenomenon is the Asian monsoon. In the summer wet SEASON, warm moist

AIR from over the Indian Ocean and South China Sea is drawn into the Asian CONTINENT, bring heavy rains, THUNDERSTORMS, and even TROPICAL CYCLONES. The wet monsoon ensures sufficient water for crops but can cause great loss of life through flooding and STORM SURGES. The dry or winter monsoon is marked by an outward flow of wind from Asia, bringing dry cooler conditions. Northern Africa and Northern Australia also experience monsoon conditions. From an Arabic word for season.

Moon. Any natural SATELLITE orbiting a PLANET. Earth has only one such satellite, which is called the Moon. Mercury and Venus have no moons, Mars has two small moons, Jupiter has sixteen known moons, Saturn has eighteen, Uranus has fifteen, Neptune has eight, and Pluto has one. Earth's Moon is 238,866 miles (384,400 km.) from Earth on average. The Moon is about one-third the size of the earth, with an equatorial diameter of 2,160 miles (3,476 km.). However, it is considerably lighter because its composition is less dense. The Moon revolves around the earth in an elliptical ORBIT every twenty-nine and a half DAYS. This corresponds to the time of one ROTATION of the Moon on its axis, so that only one side, or face, of the Moon can be seen from Earth. The Moon shines because of its ALBEDO, or reflected sunlight.

Moraine. Materials transported by a GLACIER, and often later deposited as a RIDGE of unsorted ROCKS and smaller material. Lateral moraine is found at the side of the glacier; medial moraine occurs when two gla-

Lateral and medial moraine in the French Alps. (Mark Twain, *A Tramp Abroad*, 1880) ciers join. Other types of moraine include ABLATION moraine, ground moraine, and push, RECESSIONAL, and TERMINAL MORAINE.

Morphology. This word means structure or form. Geographers study the morphology of a COUNTRY, which explains many facts about its ECONOMY, CULTURE, historical geography, and politics. Generally, five morphologies are recognized: compact, elongated, fragmented, PERFORATED, and PROTRUDED (sometimes called prorupt).

Mountain. Tall LANDFORM, rising steeply above the surrounding COUNTRY, and with a comparatively narrow SUMMIT, or top. Most mountains occur in elongated groups, as mountain CHAINS or mountain RANGES. Mountains are produced by volcanic activity or by FOLDING or faulting of the earth's CRUST. A geologic term for a period of mountain-building is an OROGENY. In some countries, "mountains" are rigidly defined by their altitudes. Great Britain, for example, historically required landforms to be 1,000 feet (305 meters) high to be classified as mountains and classified lower-ELEVATION features as HILLS.

Mountains are high, massive landforms that rise steeply above the surrounding country and have comparatively narrow summits, or tops. Most mountains occur in elongated groups, as mountain chains or mountain ranges. (PhotoDisc)

Mountain belts. Products of PLATE TECTONICS, produced by the CONVERGENCE of crustal PLATES. Topographic MOUNTAINS are only the surficial expression of processes that profoundly deform and modify the CRUST. Long after the mountains themselves have been worn away, their former existence is recognizable from the structures that mountain building forms within the ROCKS of the crust.

Mountain glacier. GLACIER in a sloping VALLEY.

Mountain material. High-standing blocks of rugged RELIEF.

Mountain pass. See PASS.

Mouth of river. The PLACE where a RIVER enters a large body of standing water, such as the OCEAN or a LAKE. There much of the river's suspended load is deposited, often forming a DELTA. Many rivers enter the SEA in an ESTUARY, a long, narrow INLET where river water mixes with tidal waters.

Mudflow. General term for a flowing mass of predominantly fine-grained earth material that possesses a high degree of fluidity during movement.

Mulatto. Person of mixed African and European ancestry.

Multiculturalism. Government policy that enables and encourages ETHNIC GROUPS to retain their distinctive CULTURE and identity, instead of being assimilated into the larger dominant culture of the society.

Multinational corporation. Organization that engages in economic activities such as mining, AGRICULTURE, manufacturing, and marketing in more than one COUNTRY, affecting the economies of those countries.

Municipality. Any URBAN political unit, such as a TOWN or CITY.

Nappe. Huge sheet of ROCK that was the upper part of an overthrust fold, and which has broken and traveled far from its original position due to the tremendous forces. The Swiss Alps have nappes in many LOCATIONS.

Narrows. STRAIT joining two bodies of water.

Nation. Term originally meaning all the citizens of a REGION, sharing cultural traits such as a common LANGUAGE, RELIGION, and ethnicity. In the times of empires in Europe, the nation had no political meaning, since political allegiance was to the monarch or emperor, and religious allegiance was to the pope. One empire would include dozens of different cultural groups, or nations. The concept of NATIONALISM arose in the nineteenth century, when various nations wanted to occupy and control their own STATES, leading to the creation of modern NATION-STATES. The establishment of the League of Nations and the United Nations reflects the growth of nationalism in the twentieth century. The term nation now commonly is used to mean the state, or political entity. Modern countries are seldom nations in the older sense, since they rarely have a homogeneous POPULATION composition, owing to IMMIGRATION or BOUNDARY changes. The word still is used in the original sense to refer to groups such as the Navaho Nation.

Nation-state. Political entity comprising a COUNTRY whose people are a national group occupying the area. The concept originated in eighteenth century France; in practice, such cultural homogeneity is rare today, even in France.

National park. Designation given to land set aside by a national government for special protection. National parks tend to have unique qualities, such as spectacular scenery, unusual land formations, or endangered species of plants or animals in need of protection.

Nationalism. Feeling of belonging to a NATION, or a group of people with a common heritage and CULTURE. The rise of nationalism led to separatist movements and uprisings and the formation of new STATES in Europe throughout the nineteenth century, and in Africa in the twentieth century.

Native Americans. Widely accepted term for the native peoples of North America, especially those of the United States. Incorporates peoples also known as American ("Red") Indians and Inuit (Eskimos). Peoples of Canada are often known as Native Canadians. See also AMERINDIANS.

Natural bridge. Bridge over an abandoned or active watercourse; in KARST TOPOGRAPHY, it may be a short CAVE or a remnant of an old, long cave.

Utah's Arches National Park is named after its many natural red sandstone bridges, carved by millions of years of erosion. (Corbis)

Natural gas. Flammable vapor found in SEDIMENTARY ROCKS, commonly, but not always, associated with CRUDE OIL; it is also known simply as gas or methane.

Natural hazard. Natural event that causes loss of human life and property and environmental destruction. Natural hazards include FLOODS, HURRICANES and TORNADOES, EARTHQUAKES, volcanic ERUPTIONS, and TSUNAMI. Flooding is the natural hazard that causes the greatest loss of life.

Natural increase, rate of. DEMOGRAPHIC MEASURE of POPULATION growth: the difference between births and deaths per year, expressed as a percentage of the POPULATION. The rate of natural increase for the United States in 2000 was 0.6 percent. In countries where the population is decreasing, the DEATH RATE is greater than the BIRTH RATE.

Natural levee. Low RIDGE deposited on the flanks of a RIVER during a FLOOD stage.

Natural resource. See RESOURCE.

Natural selection. Main process of biological evolution; the production of the largest number of offspring by individuals with traits that are best adapted to their ENVIRONMENTS.

Nautical mile. Standard MEASUREMENT at SEA, equalling 6,076.12 feet (1.85 km.). The mile used for land measurements is called a statute mile and measures 5,280 feet (1.6 km.).

Navigation. Originally, the science and art of finding a safe, short path across water, requiring determination of distance, speed, course, and position. The positions of the SUN, MOON, and stars guided early navigators. Instruments developed to aid navigators include the magnetic COMPASS and sextant. CHARTS, MAPS, and guidebooks were also valuable aids to navigation. The invention of the MARINE CHRONOMETER enabled precision in LONGITUDE. Radio position-finding and GLOBAL POSITIONING SYSTEM satellites are modern aids to navigation. Scientists also study the secrets of animal navigation. Migratory birds can navigate thousands of miles, even from one HEMISPHERE to another in the course of a year.

Neap tide. TIDE with the minimum RANGE, or when the level of the high tide is at its lowest.

Near-polar orbit. Earth ORBIT that lies in a plane that passes close to both the north and south POLES.

Nekton. PELAGIC organisms that can swim freely, without having to rely on OCEAN CURRENTS or WINDS. Nekton includes shrimp; crabs; oysters; MARINE reptiles such as turtles, crocodiles, and snakes; and even sharks; porpoises; and whales.

Net migration. Net balance of a COUNTRY or REGION'S IMMIGRATION and EMIGRATION.

Névé. French term for closely packed SNOW, deep in snowfields, from which the AIR has largely been expelled through compression due to the weight of overlying snow. Névé is an intermediate form between snow and glacial ice. It is like a series of clear bluish bands, representing the different years of snow accumulation. FIRN is the German term for this material.

Niche. In an ecological ENVIRONMENT, a position particularly suited for its inhabitant.

Nickpoint. See KNICKPOINT.

NIMBY. Acronym for "not in my back yard," in reference to movements opposing certain DEVELOPMENTS, especially in suburban areas. NIMBY-ism is generally a neighborhood action by residents who want to prevent unwanted LAND USES, protect open space, and maintain low-density housing, and block the nearby LOCATION of low-income housing or waste treatment plants, or facilities such as prisons or rehabilitation projects.

Niña, La. See LA NIÑA.

Niño, El. See EL NIÑO.

Nomadism. Lifestyle in which pastoral people move with grazing animals along a defined route, ensuring adequate pasturage and water for their flocks or herds. This lifestyle has decreased greatly as countries discourage INTERNATIONAL MIGRATION. A more restricted form of nomadism is TRANSHUMANCE.

Nomenclature. Names and terms used in a classification system.

Nonrenewable resource. RESOURCE that is exhausted after use. Includes FOSSIL FUELS, such as OIL and COAL, because the time for their formation is so long, although they are part of a biogeochemical CYCLE. See also RENEWABLE RESOURCES.

Normal fault. FAULT in which the ROCK block on top of an inclined fracture surface, also known as a FAULT PLANE, slides downward.

Normal fault in sandy shale in Tennessee's Chilhowee Mountains. (U.S. Geological Survey)

North geographic pole. Northernmost REGION of the earth, located at the northern point of the PLANET'S AXIS of ROTATION.

North magnetic pole. Small, nonstationary area in the Arctic Circle toward which a COMPASS needle points from any LOCATION on the earth.

North/south divide. Term deriving from previous centuries, when European powers controlled large colonial empires. Many of the colonies were located in the SOUTHERN HEMISPHERE, including South Africa, Australia, New Zealand, and South America. Now, the term is sometimes used to refer economically to the contrast between high-income and low-income economies. Geographically, it makes little sense to use the term north/south divide in this way, because Australia and New Zealand are in the Southern Hemisphere, but are similar economically to wealthy NORTHERN HEMISPHERE countries.

Northern Hemisphere. The half of the earth above the EQUATOR.

Notch. Erosional feature found at the base of a SEA CLIFF as a result of undercutting by WAVE EROSION, bioabrasion from MARINE organisms, and dissolution of ROCK by GROUNDWATER seepage. Also known as a nip.

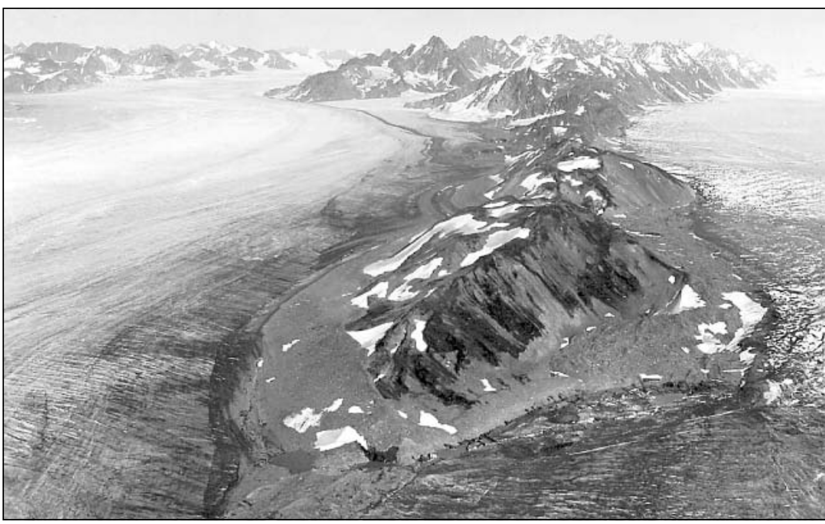
Nuclear energy. ENERGY produced from a naturally occurring isotope of uranium. In the process of nuclear FISSION, the unstable uranium isotope absorbs a neutron and splits to form tin and molybdenum. This releases more neurons, so a chain reaction proceeds, releasing vast amounts of heat energy. Nuclear energy was seen in the 1950's as the energy of the future, but safety fears and the problem of disposal of radioactive nuclear waste have led to public condemnation of nuclear power plants. Nevertheless, France generates more than half its power from nuclear energy. The alternative method of nuclear energy pro-

Nuclear power plant cooling tower. (PhotoDisc) duction is nuclear FUSION, the energy released when two smaller atomic nuclei fuse into one larger nucleus. Isotopes of hydrogen are the fuel. Fusion occurs naturally in the SUN, but humans have not harnessed nuclear fusion, except to create the hydrogen bomb.

Nuée ardente. Hot cloud of ROCK fragments, ASH, and gases that suddenly and explosively erupt from some VOLCANOES and flow rapidly down their slopes.

Numerical weather prediction. System whereby mathematical equations are used, with the aid of computers, to describe and predict atmospheric processes.

Nunatak. Isolated MOUNTAIN PEAK or RIDGE that projects through a continental ICE SHEET. Found in Greenland and Antarctica.



Nunatak surrounded by a moraine in the Alaska Gulf region. Jefferies Glacier is to the left. (U.S. Geological Survey)

Oasis. Area surrounded by DESERT, where a permanent water supply, usually from an AQUIFER, permits AGRICULTURE.

Obduction. Tectonic collisional process, opposite in effect to SUBDUCTION, in which heavier OCEANIC CRUST is thrust up over lighter CONTINENTAL CRUST.

Oblate sphere. Flattened shape of the earth that is the result of ROTATION.

Occidental. Word meaning western. It is the opposite of oriental.

Occultation. ECLIPSE of any astronomical object other than the SUN or the MOON caused by the Moon or any PLANET, SATELLITE, or ASTEROID.

Ocean. Large body of water contained in an OCEAN BASIN. Oceans cover just over 70 percent of the earth's surface. The presence of so much liquid water serves to maintain moderate TEMPERATURES. The largest ocean, the Pacific, covers almost one-third of the earth. Other oceans are the Atlantic, Indian, Arctic, and Antarctic or Southern Ocean. The edge of an ocean basin is marked by the CONTINENTAL SHELF. A small, partially enclosed area of an ocean is a SEA.

Ocean basins. Large worldwide depressions that form the ultimate RESERVOIR for the earth's water supply.

Ocean circulation. Worldwide movement of water in the SEA.

Ocean current. Predictable circulation of water in the OCEAN, caused by a combination of WIND friction, Earth's ROTATION, and differences in TEMPERATURE and density of the waters. The five great oceanic circulations, known as GYRES, are in the North Pacific, North Atlantic, South Pacific, South Atlantic, and Indian Oceans. Because of the CORIOLIS EFFECT, the direction of circulation is CLOCKWISE in the NORTHERN HEMISPHERE and COUNTERCLOCKWISE in the SOUTHERN HEMISPHERE, except in the Indian Ocean, where the direction changes annually with the pattern of winds associated with the Asian MONSOON. Currents flowing toward the EQUATOR are cold currents; those flowing away from the equator are warm currents. An important current is the warm Gulf Stream, which flows north from the Gulf of Mexico along the East Coast of the United States; it crosses the North Atlantic, where it is called the North Atlantic Drift, and brings warmer conditions to the western parts of Europe. The West Coast of the United States is affected by the cool, south-flowing California Current. The cool Humboldt, or Peru, Current, which flows north along the South American coast, is an important indicator of whether there will be an EL NIÑO event. Deep currents, below 300 feet (100 meters), are extremely complicated and difficult to study.

Oceanic crust. Portion of the earth's CRUST under its OCEAN BASINS.

Oceanic island. ISLANDS arising from seafloor volcanic ERUPTIONS, rather than from continental shelves. The Hawaiian Islands are the best-known examples of oceanic islands.

Oceanography. The science of Earth's oceans and SEAS. Physical oceanography deals with the study of seawater—TEMPERATURE, density, WAVES, and CURRENTS. Chemical oceanography deals with the chemistry of biogeochemical CYCLES of the OCEANS. MARINE geology is the study of the features of the OCEAN BASINS. Biological oceanography is the study of marine ECOLOGY, or plants and animals of the oceans.

Off-planet. Pertaining to REGIONS off the earth in orbital or planetary space.

Offshore financial centers. The global financial network is concentrated in METROPOLITAN centers, but some investors and institutions place a high value on secrecy of accounts or on sheltering RESOURCES from taxation. To meet these needs, some small countries or MICROSTATES have developed as offshore financial centers. These include the Bahamas, Vanuatu, Cayman Islands, and Bahrain, as well as the mainland countries of Luxembourg, Liechtenstein, and Belize.

Oil. Greasy substance that remains liquid at room TEMPERATURE and is insoluble in water. Oils can be obtained from plants and seeds or from the bodies of animals, but the most economically important oil today is MINERAL oil or PETROLEUM, sometimes called CRUDE OIL. This is a product created millions of years ago from the bodies of MARINE organisms that were incorporated into layers of SEDIMENTARY ROCKS. The petroleum migrated through PERMEABLE rocks to form series of RESERVOIRS that constitute an oil field. Oil is the most important of the FOSSIL FUELS.

Oligocene epoch. Geological PERIOD about 38 million years ago in the TERTIARY PERIOD of the CENOZOIC ERA.

Oort Cloud. Reservoir of long-period COMETS that exist in a spherical DISTRIBUTION far beyond the outer planetary ORBIT of the SOLAR SYSTEM. The study of this vast REGION gives scientists a better understanding of the origin of the SUN and the PLANETS.

Orbit. The path followed by an astronomical body as it moves around an attracting body. In our SOLAR SYSTEM, PLANETS move in orbits around the SUN. Smaller bodies, or SATELLITES, move in orbits around the planets. The MOON orbits the earth. The shape of an orbit is elliptical, giving rise to the earth's PERIHELION and APHELION.

Order. Group of closely related genera; in mammals, orders include the rodents, bats, and whales.

Ordovician epoch. Time PERIOD covering the interval from 505 to 438 million years ago; follows the CAMBRIAN, which covers the interval from 570 to 505 million years ago.

Ore. Type of ROCK containing MINERALS in such a concentration that mining is economically feasible. Hematite is a common ore from which iron is extracted. Galena is the principal ore for zinc. The ore is always mixed with large amounts of worthless materials known as GANGUE, so that separation is necessary to recover the mineral.

Ore deposit. Natural accumulation of MINERAL matter from which the owner expects to extract a metal at a profit.

Orient. Old European term meaning "east," for Asia.

Orogenesis. Process of mountain-RANGE formation.

Orogenic belt. MOUNTAIN BELT composed of a core of METAMORPHIC and PLUTONIC ROCKS and an adjacent THRUST BELT.

Orogeny. MOUNTAIN-building episode, or event, that extends over a period usually measured in tens of millions of years; also termed a revolution.

Orographic precipitation. Phenomenon caused when an AIR mass meets a topographic barrier, such as a mountain RANGE, and is forced to rise; the air cools to saturation, and orographic precipitation falls on the WINDWARD side as rain or SNOW. The lee side is a RAIN SHADOW. This effect is noticeable on the West Coast of the United States, which has

RAIN FOREST on the windward side of the MOUNTAINS and DESERTS on the lee.

Orography. Study of MOUNTAINS that incorporates assessment of how they influence and are affected by WEATHER and other variables.

Oscillatory flow. Flow of fluid with a regular back-and-forth pattern of motion.

Outback. Name by which Australians refer to any PLACE away from their cities. More specifically, the semiarid REGION west of the Great Dividing Range (Eastern Highlands), which covers about 80 percent of the CONTINENT, including most of Queensland, all of the Northern Territory, and all of Western Australia except the southwest corner.

Outer core. Zone in the body of the earth, located at depths of approximately 1,600 to 3,200 miles (2,900-5,100 km.), that is in a liquid state and consists of iron sulfides and iron oxides.

Overland flow. Flow of water over the land surface caused by direct PRECIPITATION.

Overurbanization. Growth of cities at such a rapid rate that they cannot sustain job creation and housing construction. Rapid in-migration from RURAL areas in low-income countries is the major cause of overurbanization. High homelessness and high unemployment result from overurbanization. URBAN POPULATION growth of this kind leads to many slums, shanties, and SQUATTER SETTLEMENTS that are illegally occupied and have few services.

Oxbow lake. LAKE created when floodwaters make a new, shorter CHANNEL and abandon the loop of a MEANDER. Over time, water in the oxbow lake evaporates, leaving a dry, curving, low-lying area known as a meander scar. Oxbow lakes are common on FLOODPLAINS. Another name for this feature is a cut-off.

Oxidation. Common chemical reaction in which elements are combined with oxygen—for example, the burning of PETROLEUM, wood, and COAL; the rusting of metallic iron; and the metabolic RESPIRATION of organisms.

Ozone. Gas containing three atoms of oxygen; it is highly concentrated in a zone of the STRATOSPHERE.

Ozone hole. Decrease in the abundance of ANTARCTIC OZONE as sunlight returns to the POLE in early springtime

Ozone layer. Narrow band of the STRATOSPHERE situated near 18 miles (30 km.) above the earth's surface, where molecules of OZONE are concentrated. The average concentration is only one in four million, but this thin layer protects the earth by absorbing much of the ultraviolet light from the SUN and reradiating it as longer-wavelength radiation. Scientists were disturbed to discover that the ozonosphere was being destroyed by photochemical reaction with CHLOROFLUOROCARBONS (CFCs). The OZONE HOLES over the South and North Poles negatively affect several animal species, including humans; skin cancer risk is increasing rapidly as a consequence of depletion of the ozone layer. Stratospheric ozone should not be confused with ozone at lower levels, which is a result of PHOTOCHEMICAL SMOG. Also called the ozonosphere.

P wave. Fastest elastic wave generated by an EARTHQUAKE or artificial ENERGY source; basically an acoustic or shock wave that compresses and stretches solid material in its path.

Pacific Rim. Group of countries with COASTLINES on the Pacific Ocean. In seeking to strengthen economic ties, these countries emphasize TRADE across the Pacific, instead of older trade links with Western Europe. Countries include the United States, Canada, Japan, Korea, China, Philippines, Australia, New Zealand, and Chile. The organization APEC was formed to exploit the growing economic strength of some Asian economies in Pacific Rim countries.

Pacific Ring of Fire. See RING OF FIRE.

Paddies. Rice fields, especially in Asian countries. The fields are small; the land must be level, with an impermeable SUBSOIL. Paddies are enclosed by low earth walls, so that they can retain the water required for flooding throughout the growing season. This type of rice growing is wet-rice cultivation. Many hillsides in Asian countries have been laboriously terraced to create small paddies on steep slopes.

Pahoehoe. See ROPY LAVA.

Paleobiogeography. Study of the geographic DISTRIBUTION of past life-forms.

Paleobiology. Study of the most ancient life-forms, typically through the examination of microscopic FOSSILS.

Paleoceanography. Study of the history of the OCEANS of the earth, ancient SEDIMENT DEPOSITION patterns, and OCEAN CURRENT positions compared to ancient CLIMATES.

Paleodepth. Estimate of the water depth at which ancient seafloor SEDIMENTS were originally deposited.

Paleomagnetism. Study of MAGNETISM preserved in ROCKS, which provides evidence of the history of Earth's MAGNETIC FIELD and the movements of CONTINENTS.

Paleontology. Study of ancient life; invertebrate paleontologists study FOSSIL invertebrate animals, vertebrate paleontologists study fossil vertebrates, and micropaleontologists study microfossils.

Paleozoic era. ERA that began about 543 million years ago and ended 245 million years ago; it includes six PERIODS: the CAMBRIAN, the ORDOVICIAN, the Silurian, the Devonian, the CARBONIFEROUS, and the PERMIAN.

Pandemic. Epidemic that spreads through a large area, sometimes even of worldwide proportions, leading to the deaths of millions of humans. The Black Death, or plague, that affected Europe in the fourteenth century was a pandemic in which it is estimated that twenty-five million people died. The Spanish Influenza Epidemic, which spread around the world during 1918 and 1919, was a pandemic, causing more than thirty million deaths. The current spread of AIDS/HIV might be described as a pandemic.

Pangaea. Name used by Alfred Wegener for the SUPERCONTINENT that broke apart to create the present CONTINENTS.

Paradigm. Pattern of scientific research and investigation that prevails in any discipline over time. A new way of conducting research or a new philosophical approach leads to a paradigm shift.

Parallel. Line of LATITUDE. One of a series of imaginary lines that extend around the earth parallel to the EQUATOR. Parallels are numbered from zero to ninety DEGREES north or south. The forty-ninth parallel forms part of the BORDER between Canada and the United States.

Parasitic cone. Small volcanic cone that appears on the flank of a larger VOLCANO, or perhaps inside a CALDERA.

Parish. Administrative subdivision of a British COUNTY or a division of the U.S. STATE of Louisiana that corresponds to the counties of other states.

Particulate matter. Mixture of small particles that adversely affect human health. The particles may come from smoke and DUST and are in their highest concentrations in large URBAN AREAS, where they contribute to the "DUST DOME." Increased occurrences of illnesses such as asthma and bronchitis, especially in children, are related to high concentrations of particulate matter.

Pass. Lower section between MOUNTAINS that enables people to travel across the mountain RANGE. It may be a saddle or, more commonly, a GORGE. The most famous is the Khyber Pass, on the BORDER between Afghanistan and Pakistan, which has been the entryway for numerous invasions of the Indian SUBCONTINENT. The Simplon Pass allowed traverse of the Swiss Alps between northern and southern Europe, but it has been superseded by the Simplon Tunnel. The Donner Pass in the Sierra Nevada is named after the expedition leaders, George and Jacob Donner, whose party of immigrants was snowbound there in the winter of 1846-1847, leading some members to survive on the dead bodies of their companions. Also called a mountain pass.

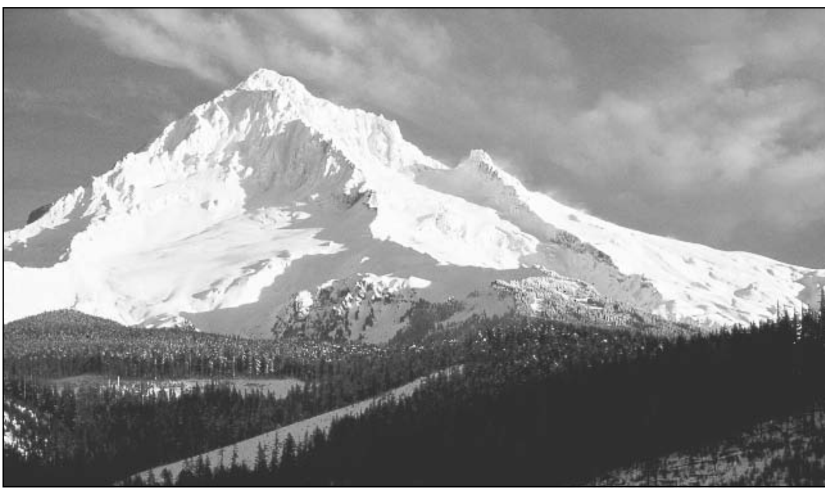
Pastoralism. Type of AGRICULTURE involving the raising of grazing animals, such as cattle, goats, and sheep. Pastoral nomads migrate with their domesticated animals in order to ensure sufficient grass and water for the animals.

Paternoster lakes. Small circular LAKES joined by a STREAM. These lakes are the result of glacial EROSION. The name comes from the resemblance to rosary beads and the accompanying prayer (the Our Father).

Patriarchy. Society in which men dominate all aspects of life, which can mean the oppression and exploitation of women. Fathers dominate the household and family group, and adult men have absolute authority over the larger social group. The early studies of patriarchy used ancient Greece and Rome as models. In practice, however, women had considerable power in those societies. Ethnographers and anthropologists have shown that there are many types of social arrangements that are complex and cooperative, rather than dominated entirely by one sex. Most feminists are opposed to patriarchal arrangements.

Patterned ground. Networks of rocks brought to the surface in polygon patterns by freeze-thaw cycles in arctic environments. See also PERIGLACIAL; PERMAFROST.

Peak. MOUNTAIN, or part of a mountain, that has a sharply defined SUMMIT. Some mountains, such as Africa's Mount Kilimanjaro, have more than a single peak.



A peak is mountain, or part of a mountain, that has a sharply defined summit, in contrast to hills and mountains with smooth domes. (PhotoDisc)

Peat. Organic material formed in cool humid CLIMATES, where VEGETATION has accumulated and partially decomposed under boggy or waterlogged conditions. It is an early stage in the formation of COAL. Peat is found extensively on all northern CONTINENTS and can be used as a fuel if it is dried before burning. Peat has been an important source of ENERGY in Ireland.

Pebble. On the SCALE developed by C. K. Wentworth, a pebble is a particle or piece of ROCK with a diameter between .16 and 2.5 inches (4 and 64 millimeters). Coarser material is cobbles; finer material is GRANULES. Pebbles are an important product of FLUVIAL EROSION. They are part of the formation of POTHOLES.

Pedestal rock. Rock that has assumed the shape of a pedestal as a result of unique shaping processes caused by WIND.

Pediment. In DESERT REGIONS, there is often a gently sloping BEDROCK surface extending along the base of a mountain RANGE, sometimes covered with a thin layer of ALLUVIUM. This EROSION surface is a special case of a PIEDMONT, which was given the name pediment. An extensive pediment has been called a pediplain.

Pediplain. See PEDIMENT.

Pedology. Scientific study of SOILS.

Pelagic. Relating to life-forms that live on or in open SEAS, rather than waters close to land.

Pele. The Hawaiian goddess of fire, attributed with the creation of the ISLANDS of Hawaii. When strong WINDS blow pieces of LAVA from a lava fountain, drawing them out into long thin threads, the delicate volcanic forms are called Pele's hair.

Peneplain. In the geomorphic CYCLE, or cycle of LANDFORM development, described by W. M. Davis, the final stage of EROSION led to the creation of an extensive land surface with low RELIEF. Davis named this a peneplain, meaning "almost a plain." It is now known that tectonic forces are so frequent that there would be insufficient time for such a cycle to complete all stages required to complete this landform.

Peninsula. Narrow strip of land extending from the mainland into the SEA or OCEAN. From the Latin word meaning "almost an ISLAND."

Percolation. Downward movement of part of the water that falls on the surface of the earth, through the upper layers of PERMEABLE SOIL and ROCKS under the influence of GRAVITY. Eventually, it accumulates in the zone of SATURATION as GROUNDWATER.

Perennial lake. LAKE that contains water year-round. See also INTERMITTENT LAKE.

Perennial stream. RIVER that has water flowing in it throughout the year. See also INTERMITTENT STREAM.

Perforated state. STATE whose territory completely surrounds another state. The classic example of a perforated state is South Africa, within which lies the COUNTRY of Lesotho. Technically, Italy is perforated by the MICROSTATES of San Marino and Vatican City.

Periglacial. Landforms and processes found over one fifth the surface of the earth, along the margins of past and present GLACIERS. See also PERMAFROST; PATTERNED GROUND

Perihelion. Point in Earth's REVOLUTION when it is closest to the SUN (usually on January 3). At perihelion, the distance between the earth and the Sun is 91,500,000 miles (147,255,000 km.). The opposite of APHELION.

Period. Unit of geologic time comprising part of an ERA and subdivided, in decreasing order, into EPOCHS, ages, and chrons.

Periodicity. The recurrence of related phenomena at regular intervals.

Periphery. Geographic study of a COUNTRY or REGION can identify a core area or focus of human activity, where there is a concentration of POPulation, wealth, production, and consumption. A country's CORE REGION is usually its CAPITAL CITY and nearby region. Other parts of the country are the periphery and have the disadvantage of lower levels of DEVELOPMENT and investment. The concept can be applied to the whole world: There is a small core of countries with high national incomes and advanced living standards (Japan, the United States, Canada, and countries in Western Europe), and a large peripheral area of the rest of the world, where underdevelopment, hunger, poverty, and lack of education prevail. Countries in the periphery have no control of the global economic system and rely on the export of raw materials and cash crops to the core, or on the exploitation of their workers in low-wage labor.

Permafrost. Permanently frozen SUBSOIL. The condition occurs in perennially cold areas such as the ARCTIC. No trees can grow because their roots cannot penetrate the permafrost. The upper portion of the frozen SOIL can thaw briefly in the summer, allowing many smaller plants to thrive in the long daylight. Permafrost occurs in about 25 percent of the earth's land surface, and the condition even hampers construction in REGIONS such as Siberia and ARCTIC Canada. See also PATTERNED GROUND; PERIGLACIAL.

Exposed permafrost in Labrador's Katherine River Valley of the Torngat Mountains. (Geological Survey of Canada)

Permeable. Materials that can be penetrated by liquids or gases, such as porous ROCKS, are called permeable.

Permian period. Most recent PERIOD of the PALEOZOIC ERA, lasting from approximately 280 to 225 million years ago.

Perturb. To change the path of an orbiting body by a gravitational force.

Petrified wood. Form of FOSSIL wood in which all the original tissue and structure of the tree has been replaced by SILICA or calcite. It is produced when waterlogged tree trunks are buried in SAND, or also if trees are covered by VOLCANIC ASH. The Petrified Forest of Arizona is a famous REGION of the United States preserved as a NATIONAL PARK. Here the tree tissue has been replaced by chalcedony, a form of QUARTZ.

Petrified tree trunk, photographed around 1890, on Specimen Ridge, Yellowstone National Park. (U.S. Geological Survey)

Petrochemical. Chemical substance obtained from NATURAL GAS or PETROLEUM.

Petrography. Description and systematic classification of ROCKS.

Petroleum. Commonly used alternative term for CRUDE OIL; technically, the word refers to the mixture of complex hydrocarbons that can exist as gas (NATURAL GAS), liquid (OIL), and solid (bitumen). In the twentieth century, oil and natural gas were the most important FOSSIL FUELS. Petroleum formed from the altered remains of single-celled planktonic organisms accumulated deep in SEDIMENTARY ROCKS such as SHALE and CLAY, before migrating to porous RESERVOIR ROCKS. Most of the more than fifty thousand oilfields in the world are small. Although the United States is a major oil producer, it is also the world's largest consumer, so it is heavily reliant on imported oil. From a Greek word for rock oil.

Phanerozoic eon. PERIOD of geologic time with an abundant FOSSIL RECORD, extending from about 544 million years ago to the present.

Photochemical smog. Mixture of gases produced by the interaction of sunlight on the gases emanating from automobile exhausts. The gases include OZONE, nitrogen dioxide, carbon monoxide, and peroxyacetyl nitrates. Many large cities suffer from poor AIR quality because of photochemical smog. Severe health problems arise from continued exposure to photochemical smog.

Photometry. Technique of measuring the brightness of astronomical objects, usually with a photoelectric cell.

Photosynthesis. Process by which green plants capture light ENERGY—generally INSOLATION—and convert it into chemical compounds known as sugars (starches, hydrocarbons) that provide energy for the plants to grow. Hydrogen from water and carbon from the ATMOSPHERE combine with oxygen in these energy-rich compounds. Water and CARBON DIOXIDE from the atmosphere are essential for photosynthesis. Oxygen is the other product of photosynthesis. Without photosynthesis, life on Earth would be impossible. Plants, which rely on photosynthesis for growth, form the basis of any FOOD CHAIN, so organisms, including humans, would not survive without it. The opposite of photosynthesis is RESPIRATION.

Phylogeny. Study of the evolutionary relationships among organisms.

Phylum. Major grouping of organisms, distinguished on the basis of basic body plan, grade of anatomical complexity, and pattern of growth or development.

Physical geography. The study of the natural world, including GEOMORPHOLOGY, CLIMATOLOGY, BIOGEOGRAPHY, SOILS, and aspects of MARINE studies and environmental science. Physical geographers are especially interested in the relationship between humans and the natural world.

Physical weathering. The breaking down or disintegrating of ROCK into smaller pieces. In cold CLIMATES, or in high-ALTITUDE REGIONS where TEMPERATURES fall below zero at night, FROST WEDGING is an important form of physical weathering, which causes rocks to shatter as water freezes into ice in JOINTS in rocks. EXFOLIATION or the peeling off of sheets of rock through pressure release is another form of physical weathering.

Physiography. The PHYSICAL GEOGRAPHY of a PLACE—the LANDFORMS, water features, CLIMATE, SOILS, and VEGETATION.

Physiologic density. Measure of agricultural productivity—the number of people of a COUNTRY who are fed per unit area of ARABLE, or agricultural, land. Several countries have a much higher physiological density than the United States, but they also have either higher POPULATIONS, less arable land, or both.

Piedmont. LANDFORM at the foot of a MOUNTAIN. In arid REGIONS, it is easy to observe the piedmont angle—the sharp change in angle of slope between the flat DESERT PLAIN and the adjacent mountains. Piedmont can be an erosional surface, cut into a BEDROCK surface called a PEDIMENT, or a depositional surface, formed as STREAMS emerge from the mountains and deposit their load as ALLUVIAL FANS. A series of coalescing alluvial fans form a sloping piedmont called a *bajada*. The name "piedmont" comes from the Piedmont of northern Italy, which comprises the Po River Valley. In the United States, the long region of dissected PLATEAU lying just east of the Appalachian Mountains, from New Jersey to Alabama, is called the Piedmont; it contains some of the richest farmland of that COUNTRY.

Piedmont glacier. GLACIER formed when several ALPINE GLACIERS join together into a spreading glacier at the base of a MOUNTAIN or RANGE. The Malaspina glacier in Alaska is a good example of a piedmont glacier.

Alaska's Malaspina Glacier, with the Mount St. Elias range in the background. (U.S. Geological Survey)

Piedmont lake. LAKE formed when glacial MORAINE, or deposited material, DAMS up a STREAM flowing in a former glacial TROUGH. Several lakes forming the Lake District of England are piedmont lakes.

Pilgrimage. Journey to a sacred SITE or to a PLACE of religious importance, such as a shrine, undertaken by believers of that faith. The *hajj*, or pilgrimage to Mecca, is especially important for the RELIGION of ISLAM. Christian pilgrimages to Jerusalem have been made for almost two millennia. The most important site for Buddhist pilgrims is Bodh Gaya in India, where Prince Siddhartha attained enlightenment.

Pillow lava rocks from off the shore of the island of Hawaii. (National Oceanic and Atmospheric Administration)

Pillow lava. Substance formed when a VOLCANO emits fluid ROPY LAVA, also known as pahoehoe, into the SEA, where the rapid cooling forms a skin, producing small rounded shapes like pillows, one after another, in a budding process.

Place. In geographic terms, space that is endowed with physical and human meaning. Geographers study the relationship between people, places, and ENVIRONMENTS. The five themes that geographers use to examine the world are LOCATION, place, human/environment interaction, movement, and REGIONS.

Placer. Accumulation of valuable MINERALS formed when grains of the minerals are physically deposited along with other, nonvaluable mineral grains.

Plain. Area of land that has low RELIEF or is almost flat. Difference in ELEVATION on a plain is less than 325 feet (100 meters) and the slope angle is less than five DEGREES. Most plains were formed by DEPOSITION, especially by RIVERS during FLOOD. FLOODPLAINS became favored LOCATIONS early in human history because the flat land was suitable for AGRICULTURE, building construction, and ease of transport. Almost one-third of the earth's land surface is plains. The Great Plains of North America extend from the Gulf of Mexico to Hudson Bay. Plains cover Europe from Poland to the Ural Mountains in Russia. South America has extensive plains, especially in Brazil and Argentina.

Plane of the ecliptic. See ECLIPTIC, PLANE OF.

Planet. Celestial body that revolves in an ORBIT around a star. This definition excludes MOONS, METEOROIDS, and COMETS. Our SOLAR SYSTEM has nine planets, of which Earth is the third-closest to the SUN. The other planets (in order from the Sun) are Mercury, Venus, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. The inner four planets are called TERRESTRIAL PLANETS because they are made of solid ROCKS; the next four are the Jovian, or giant, planets made of gas.

Planetary wind system. Global atmospheric circulation pattern, as in the BELT of prevailing westerly WINDS.

Plankton. Organisms living in FRESH WATER or OCEANS that are too tiny to swim against CURRENTS or WIND and so can only float. Plankton can be subdivided based on life-forms into phytoplankton, or plantlike plankton, and zooplankton, or animal-like plankton. The crustacean zooplankton known as krill are the most important part of the MARINE plankton, because they are the food source for the great whales. Plankton also can be classified based on size. Macroplankton are greater than 0.4 inch (1 centimeter) in length, microplankton can be as small as a twentieth of that size, and nannoplankton are ten times smaller still. Organisms that can swim are called NEKTON.

Plankton are marine organisms so small they cannot swim against currents or wind and must therefore merely float where the water takes them. Under certain conditions, the numbers of organisms can explode, creating what is called a plankton bloom that is visible from space, as is this example off the coast of Namibia in the South Atlantic Ocean in April, 1985. (Corbis)

Plant communities. See BIOME.

Plantation. Form of AGRICULTURE in which a large area of agricultural land is devoted to the production of a single cash crop, for export. Many plantation crops are tropical, such as bananas, sugarcane, and rubber. Coffee and tea plantations require cooler CLIMATES. Formerly, slave labor was used on most plantations, and the owners were usually Europeans.

Plat. General term for any small piece of land. Also used for a MAP showing features within a MUNICIPALITY.

Plate. Relatively thin slab of crustal ROCK, either continental or oceanic, that moves over the face of the globe, driven by currents of circulating molten rock in the underlying MANTLE. See also TECTONIC PLATE.

Plate boundary. REGION in which the earth's crustal PLATES meet, as a converging (SUBDUCTION ZONE), diverging (MID-OCEAN RIDGE), TRANSFORM FAULT, or collisional interaction.

Plate tectonics. Theory proposed by German scientist Alfred Wegener in 1910. Based on extensive study of ancient geology, STRATIGRAPHY, and CLIMATE, Wegener concluded that the CONTINENTS were formerly one single enormous LANDMASS, which he named PANGAEA. Over the past 250 million years, Pangaea broke apart, first into LAURASIA and GONDWANALAND, and subsequently into the present continents. Earth scientists now believe that the earth's CRUST is composed of a series of thin, rigid PLATES that are in motion, sometimes diverging, sometimes colliding.

Plateau. Large area of flat land at high ELEVATION and surrounded by ESCARPMENTS. Plateaus and enclosed BASINS cover about 45 percent of the earth's land surface. The flat top often results from a hard layer of ROCK at the surface. The Colorado River has eroded the Grand Canyon into the Kaibab Plateau. A similar but smaller feature is a TABLELAND. The highest plateau is in Tibet (Xizang), where the elevation is around 14,500 feet (4,500 meters). A plateau can be formed by thermal expansion or UPLIFT by underlying hot MAGMA. The large plateaus of East Africa were formed in this way. Plateaus can also be formed by volcanic ERUPTION of huge amounts of LAVA, known as flood BASALT. The Deccan Plateau of India and the Columbian Plateau of the United States are good example of this type of plateau. Some plateaus are part of a mountain RANGE, for example, the ALTIPLANO in South America's Andes.

Playa. Shallow but broad SALINE LAKE, perhaps only a few centimeters deep, found in DRAINAGE BASINS in arid and semiarid REGIONS. A playa may dry up to form a salina, or SALT flat. Playas in the Western United States are sometimes called ALKALI FLATS.

Pleistocene. EPOCH of geological time extending from about 1.6 million years ago to about 10,000 years ago. Broadly speaking, the Pleistocene corresponded to the great ICE AGES of the earth, although it is now thought that the cooling began earlier. During the Pleistocene, almost one-third of the earth's land surface was covered by glacial ice. Now only about 10 percent is covered, mainly in Antarctica and Greenland. After the Pleistocene comes the HOLOCENE Epoch; preceding the Pleistocene was the PLIOCENE.

Plinian eruption. Rapid ejection of large volumes of VOLCANIC ASH that is often accompanied by the collapse of the upper part of the VOLCANO. Named either for Pliny the Elder, a Roman naturalist who died while observing the ERUPTION of Mount Vesuvius in 79 C.E., or for Pliny the Younger, his nephew, who chronicled the eruption.

Pliocene epoch. Geological EPOCH in TERTIARY PERIOD of the CENOZOIC ERA that began about 12 million years ago.

Plucking. Term used to describe the way glacial ice can erode large pieces of ROCK as it makes its way downslope. The ice penetrates JOINTS, other openings on the floor, or perhaps the side wall, and freezes around the block of stone, tearing it away and carrying it along, as part of the glacial MORAINE. The rocks contribute greatly to glacial ABRASION, causing deep grooves or STRIATIONS in some places. The jagged torn surface left behind is subject to further plucking. ALPINE GLACIERS can erode steep VALLEYS called glacial TROUGHS.

Plume. Expanded and cooled material pushed upward in the form of a fireball from the force of an ERUPTION or impact.

The plume of an erupting volcano is similar in appearance to that of an atomic bomb explosion. (PhotoDisc)

Plural society. Society in which more than one ETHNIC GROUP lives, with distinct separation of the different CULTURES. The United States and Canada are plural societies.

Pluton. Generic term for an IGNEOUS body that solidifies well below the earth's surface; PLUTONIC ROCKS are coarse-grained because they cool slowly.

Plutonic. IGNEOUS ROCKS made of MINERAL grains visible to the naked eye. These igneous rocks have cooled relatively slowly. GRANITE is a good example of a plutonic rock.

Pluvial period. Episode of time during which rains were abundant, especially during the last ICE AGE, from a few million to about ten thousand years ago.

Polar ice cap. Large sheet of ice, often more than a hundred square miles in size, that covers the polar portions of the Arctic Ocean and does not melt seasonally.

Polar stratospheric clouds. CLOUDS of ice crystals formed at extremely low TEMPERATURES in the polar STRATOSPHERE.

Polar vortex. Closed atmospheric circulation pattern around the South Pole that exists during the winter and early spring; atmospheric mixing between the polar vortex and REGIONS outside the vortex is slow. The low-pressure system has swirling WINDS at its boundaries.

Polarity. Orientation of the earth's MAGNETIC FIELD relative to the earth.

Polder. Lands reclaimed from the SEA by constructing DIKES to hold back the sea and then pumping out the water retained between the dikes and the land. Before AGRICULTURE is possible, the SOIL must be specially treated to remove the SALT. Some polders are used for recreational land; cities also have been built on polders. The largest polders are in the Netherlands, where the northern part, known as the Low Netherlands, covers almost half of the total area of this COUNTRY.

Pole. The ends of the earth's AXIS of ROTATION are termed the North and South Pole, respectively. The geographic pole does not correspond exactly with the MAGNETIC POLE, because the earth's MAGNETIC FIELD is in constant change. Norwegian explorer Roald Amundsen was the first to reach the South Pole, in 1911. American explorer Robert E. Peary claimed to have reached the North Pole in 1909. Richard E. Byrd flew over the North Pole in 1926.

Political geography. Study of spatial aspects of political processes, mainly at the international scale. It includes the spatial analysis of various political ideologies, BOUNDARY changes, forms of government, selection of CAPITAL cities, and relations between STATES.

Pollution. Environmental pollution is the introduction of unwanted and usually unhealthful materials into the ENVIRONMENT—the ATMOSPHERE, SOIL, or water. Some pollutants occur naturally: VOLCANOES and naturally occurring FOREST fires emit DUST and vapors into the atmosphere. Of greater concern is anthropogenic pollution, or human pollution of the environment. When the human POPULATION was small, this was not a problem, but six billion humans now produce vast amounts of human waste (sewage) and garbage. AIR POLLUTION is especially bad in many cities, such as Mexico City and Bangkok, where noxious gases are produced by vehicles and ENERGY sources. Human activities such as farming can increase dust particles, and human-caused forest fires are a major source of air pollution. Industrial products such as pesticides or CFCs (CHLOROFLUOROCARBONS) spread far from their source areas. Water pollution comes from sewage disposal and RUNOFF from cities, industries, and agricultural lands; THERMAL POLLUTION occurs from nuclear power plants. Land pollution generally involves solid waste, such as nonbiodegradable trash, but also includes chemicals such as DDT or PCBs.

Polygenetic. Pertaining to volcanism from several physically distinct vents or repeated ERUPTIONS from a single vent punctuated by long periods of quiescence.

Polygonal ground. Distinctive geological formation caused by the repetitive freezing and thawing of PERMAFROST.

Pool. Small but comparatively deep body of water, or a slow-moving part of a STREAM.

Popular culture. Term for the products and LANDSCAPES created, used, and enjoyed by people in their everyday lives. Popular culture is similar to folk culture and is the opposite of high culture.

Population. Human population refers to the number of people inhabiting an area, such as a COUNTRY. The population of the United States in May, 2000, was estimated to be 274,863,982. The population of the earth then was estimated at 6,072,255,639. In biology, population refers to the number of individuals of one species in a given area, for example the wolf population of Yellowstone National Park. Population size is limited by availability of food and water, disease, and other factors.

Population density. DEMOGRAPHIC MEASURE calculated as the total POPULATION of a COUNTRY or other territory divided by it total area. The resultant figure gives the number of residents per square mile or square kilometer. The United States had a population density of about 75 persons per square mile in the year 2000. Population density figures can be misleading, especially for large countries, since people are not distributed evenly throughout any country. In the United States, there are large clusters of dense population, such as the Los Angeles conurbation, where the population density is much higher then the average for the country; there also are huge REGIONS with almost no residents, such as in the STATES of Utah, Nevada, and Montana, where the population density is very low.

Population explosion. Great increase in the number of people in a short period, due to a large number of births with a high survival rate. The first human population explosion occurred about three thousand years ago, as a result of the AGRICULTURAL REVOLUTION. When many humans changed their lifestyle from HUNTING AND GATHERING to raising crops and domesticated animals, the increased food supply made this population explosion possible. The next great population explosion occurred in the eighteenth century, as a result of the INDUSTRIAL REVOLUTION in Europe. This explosion has continued. In the year 2000, there were more than six billion people on Earth, and this number was predicted to double in fifty years.

Population pyramid. Type of bar graph that displays the age and sex structure of a given POPULATION. A pyramid shape means that the sexes are evenly distributed; the greater numbers of the population are children, with correspondingly smaller numbers for each older age group; and there is continued population growth. Some rapidly growing countries have oversteepened population pyramids. Pyramids for countries with slow or no population growth have a smaller base than the middle sections that represent the adult population.

Porosity. The space in a ROCK or SOIL that is filled with AIR. This pore space occurs between the grains or crystals that make up the rock. Porosity is related to grain size, smoothness, and compaction of materials.

Port. PLACE on a COAST where ships can be securely anchored or tied up, safe from STORMS, while they load or unload cargo or passengers. As ships have become larger, many older ports have lost their economic function and large artificial HARBORS have been constructed in their place. The historic English Cinque Ports were Dover, Hastings, Hythe, New Romney, and Sandwich; only Dover remained important at the end of the twentieth century.

Possibilism. Concept that arose among French geographers who rejected the concept of ENVIRONMENTAL DETERMINISM, instead asserting that the relationship between human beings and the ENVIRONMENT is interactive.

Postindustrial economy. Concept introduced by American sociologist Daniel Bell, referring to the fact that the majority of the workforce in highly developed, high-income countries is employed in service industries. This is the result of increased disposable income and increased leisure time. Rapid growth of knowledge-based industries and information TECHNOLOGY has increased the importance of TERTIARY INDUSTRY and the QUATERNARY SECTOR, while the proportion of the workforce in SECONDARY INDUSTRY continues to decline. In such societies, education, health services, and the welfare state assume new dominance, while science and knowledge-based enterprises flourish.

Potable water. FRESH WATER that is being used for domestic consumption.

Potholes. Circular depressions formed in the bed of a RIVER when the STREAM flows over BEDROCK. The scouring of PEBBLES as a result of water TURBULENCE wears away the sides of the depression, deepening it vertically and producing a smooth, rounded pothole. (In modern parlance, the term is also applied to holes in public roads.)

Prairie. Flat PLAINS covered with grasses, found in North America. The annual RAINFALL decreases from east to west, and the VEGETATION changes correspondingly from tall-grass prairie through mixed prairie to short-grass prairie. The tall-grass prairie is an area of extremely rich SOILS, and the original vegetation has largely been cleared for grain farming of wheat or corn, or for URBAN purposes; the short-grass prairie is largely used for pastoral AGRICULTURE, especially raising cattle for beef. Prairie animals include the bison, wolf, prairie chicken, prairie dog, coyote, jackrabbit, and many birds. The Canadian PROVINCES of Alberta, Manitoba, and Saskatchewan are called the Prairie Provinces. The prairie BIOME is part of the middle LATITUDE GRASSLAND biome, which includes the Pampas of Uruguay and the grasslands of the Ukraine.

Prairie is the term applied to flat plains covered with grasses—a terrain that predominates throughout North America's Great Plains. (PhotoDisc)

Precambrian period. The oldest and longest time in Earth's geologic history. It began around 3.9 billion years ago—the age of the oldest known ROCKS on Earth—and continued to the beginning of the PALEOZOIC ERA, 543 million years ago. The name was given after the earliest FOSSILS were found in rocks in Wales (Cambria). It was assumed that life on Earth began in the CAMBRIAN PERIOD. Study in the twentieth century revealed that life has existed on Earth for perhaps 3.5 billion years. Because of greater knowledge, the Precambrian is now divided into the Archean and PROTEROZOIC EONS. The Precambrian period accounts for almost 80 percent of Earth's geologic history.

Precipitation. All water that falls from CLOUDS to the ground, whether in liquid or solid form. Water in the ATMOSPHERE collects around particles called CONDENSATION NUCLEI, forming cloud droplets that grow in size through collision and coalescence. The precipitation particles eventually become so large and heavy that they fall to the ground. Types of precipitation include SNOW, rain, SLEET, and hail. Snow is a solid, crystalline form of water. Rain is liquid water drops with diameters greater than 0.02 inch (0.5 millimeter). When the drops are smaller, the precipitation is usually called DRIZZLE. Sleet is frozen raindrops or partially melted snowflakes. Hail is balls or pieces of ice with a diameter of larger than 0.2 inch (5 millimeters). Small hail is sometimes called ice pellets.

Primary economic activity. Economic activities that derive their materials directly from the ENVIRONMENT. These include hunting, fishing, forestry, farming, mining, and quarrying. In low-income economies, the majority of the POPULATION is engaged in primary industry. In the poorest countries, this is usually SUBSISTENCE AGRICULTURE. Also called primary industries.

Primary minerals. MINERALS formed when MAGMA crystallizes.

Primary wave. Compressional type of EARTHQUAKE wave, which can travel in any medium and is the fastest wave.

Primate city. CITY that is at least twice as large as the next-largest city in that COUNTRY. The "law of the primate city" was developed by American geographer Mark Jefferson, to analyze the phenomenon of countries where one huge city dominates the political, economic, and cultural life of that country. The concept is easily understood when one thinks of Paris, a classic example of a primate city; London is another great primate city. The size and dominance of a primate city is a PULL FACTOR and ensures its continuing dominance. Not all countries have a primate city. The United States does not, because there are similar-sized agglomerations on the East Coast (New York) and the West Coast (Los Angeles), neither of which is the national CAPITAL city. It is not necessary for a primate city to be a national capital, but in practice this is the case. Australia is another country with no primate city. Instead, it has two large cities, Sydney and Melbourne, neither of which is the capital city.

Prime meridian. Line of LONGITUDE used as a reference for the geographic GRID. It is numbered zero and separates the EASTERN and WESTERN HEMISPHERES. Other MERIDIANS are numbered from 1 to 180 DEGREES, east and west, of the prime meridian. The prime meridian line is also called the Greenwich meridian because it runs through the former Royal Observatory at Greenwich, near London, England, connecting the North and South Poles. Although other cities, such as Paris and Washington, D.C., vied to be the LOCATION of the prime meridian, the decision was made in 1884 at the International Meridian

Conference in Washington, D.C. Great Britain then had the world's largest empire and the largest navy.

Principal parallels. The most important lines of LATITUDE. PARALLELS are imaginary lines, parallel to the EQUATOR. The principal parallels are the equator at zero DEGREES, the tropic of CANCER at 23.5 degrees North, the tropic of CAPRICORN at 23.5 degrees south, the Arctic Circle at 66.5 degrees north, and the Antarctic Circle at 66.5 degrees south.

Principality. Literally, the territory governed by a prince; any monarch's REALM.

Prorupt. See PROTRUDED.

Protectorate. COUNTRY that is a political DEPENDENCY of another NATION; similar to a COLONY, but usually having a less restrictive relationship with its overseeing power.

Proterozoic eon. Interval between 2.5 billion and 544 million years ago. During this PERIOD in the GEOLOGIC RECORD, processes presently active on Earth first appeared, notably the first clear evidence for PLATE TECTONICS. ROCKS of the Proterozoic eon also document changes in conditions on Earth, particularly an apparent increase in atmospheric oxygen.

Protruded. The MORPHOLOGY of a COUNTRY can be described as protruded when the main body of the country has a long thin extension stretching away from it. Thailand is a protruded country. The STATE of Oklahoma can be described as protruded. An alternative term is prorupt.

Province. Term used in some countries for internal administrative subdivisions. Canada, for example, has ten provinces. When South Africa was reorganized in 1994, it changed from four to nine provinces.

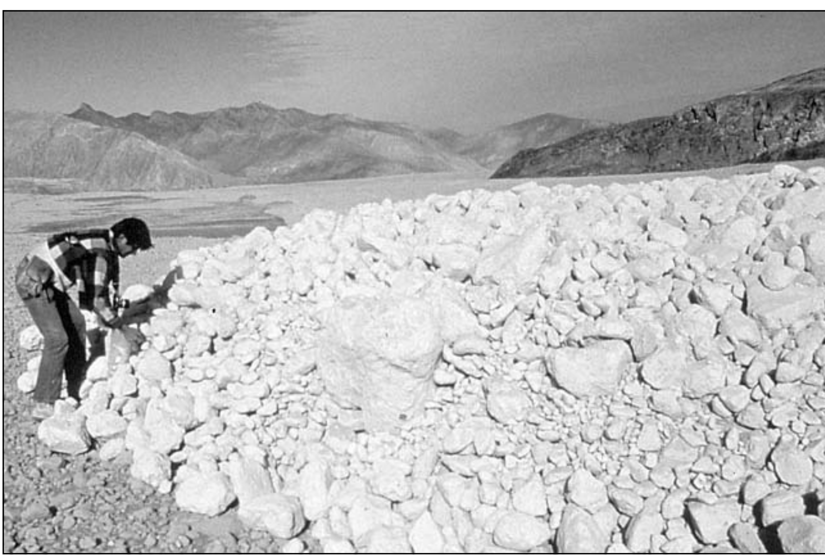
Psychrometer. Device used to measure and calculate the RELATIVE HUMIDITY of AIR. The sling psychrometer consists of two THERMOMETERS, one of which has its bulb wrapped in moistened cloth. The psychrometer is swung in the air, and the difference in TEMPERATURE of the two bulbs is calculated. This is compared with the psychrometric table, which gives the relative humidity value corresponding to those conditions.

Pull factors. Forces that attract immigrants to a new COUNTRY or LOCATION as permanent settlers. They include economic opportunities, educational facilities, land ownership, gold rushes, CLIMATE conditions, democracy, and similar factors of attraction.

Pumice. Light, porous ROCK of IGNEOUS origin. It is formed when ejected LAVA cools rapidly without crystallization. In this respect, pumice is similar to obsidian, or volcanic glass. Heating obsidian can produce pumice. The expulsion of gases in the lava causes the rock to swell, or froth, as it cools. Visually, pumice resembles some SEA sponges. It is pale gray to whitish in color and is so light that it floats in water. Countries around the Mediterranean Sea mine pumice commercially. Pumice from Peru is widely used in the fashion industry to create the "stone-washed" look of clothing items.

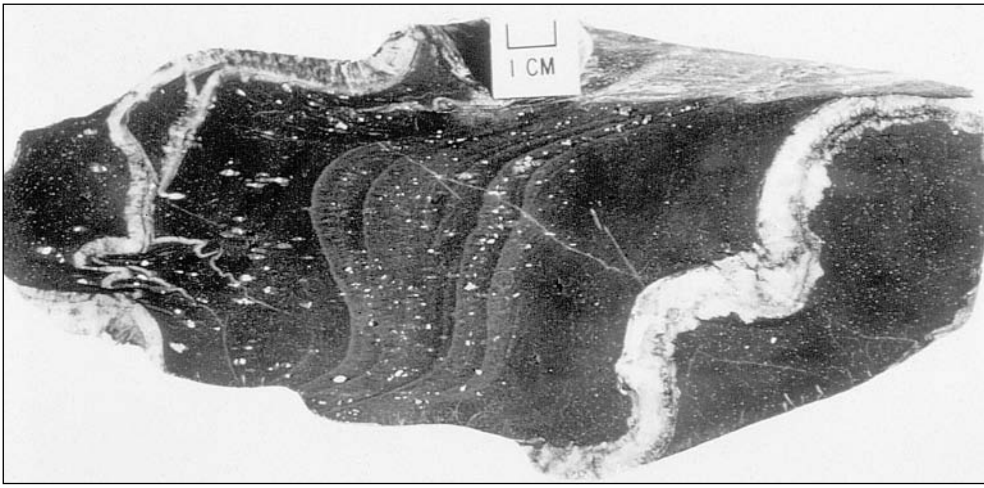
Push factors. Forces that encourage people to migrate permanently from their HOMELANDS to settle in a new destination. They include war, persecution for religious or political reasons, hunger, and similar negative factors.

Pyroclasts. Materials that are ejected from a VOLCANO into the AIR. Pyroclastic materials return to Earth at greater or lesser distances, depending on their size and the height to which they are thrown by the explosion of the volcano. The largest pyroclasts are volcanic bombs. Smaller pieces are volcanic blocks and scoria. These generally fall back onto the volcano and roll down the sides. Even smaller pyroclasts are LAPILLI, cinders, and VOLCANIC ASH. The finest pyroclastic materials may be carried by WINDS for great distances, even completely around the earth, as was the case with DUST from the Krakatoa explosion in 1883 and the early 1990's explosions of Mount Pinatubo in the Philippines.



Pyroclastic flow deposit. (U.S. Geological Survey)

Qanat. Method used in arid REGIONS to bring GROUNDWATER from mountainous regions to lower and flatter agricultural land. A qanat is a long tunnel or series of tunnels, perhaps more than a mile long. The word *qanat* is Arabic, but the first qanats are thought to have been constructed in Farsi-speaking Persia more than two thousand years ago. Qanats are still used there, as well as in Afghanistan and Morocco.



The simple oxide quartz (the lighter buckled veins in this rock sample) is the most common of the silicate minerals, which constitute 95 percent of Earth's crust. (Geological Survey of Canada)

Quartz. One of the most common MINERALS on the earth's surface; it occurs in many different forms, including agate, jasper, and chert.

Quaternary period. The shortest and youngest of the eleven PERIODS into which geologic time is divided. The Quaternary began around 1.6 million years ago and continues at the present. It comes after the TERTIARY PERIOD, which extended from 66.4 million years ago to 1.6 million years ago. The Quaternary is subdivided into the PLEISTOCENE and HOLOCENE EPOCHS. We are living in the Holocene Epoch.

Quaternary sector. Economic activity that involves the collection and processing of information. The rapid spread of computers and the Internet caused a major increase in the importance of employment in the quaternary sector. See also POSTINDUSTRIAL ECONOMY.

Radar imaging. Technique of transmitting radar toward an object and then receiving the reflected radiation so that time-of-flight MEASUREMENTS provide information about surface TOPOGRAPHY of the object under study.

Radial drainage. The pattern of STREAM courses often reveals the underlying geology or structure of a REGION. In a radial drainage pattern, streams radiate outward from a center, like spokes on a wheel, because they flow down the slopes of a VOLCANO.

Radiation. Transfer of ENERGY through a transparent medium, as occurs when the SUN warms the earth.

Radioactive minerals. MINERALS combining uranium, thorium, and radium with other elements. Useful for nuclear TECHNOLOGY, these minerals furnish the basic isotopes necessary not only for nuclear reactors but also for advanced medical treatments, metallurgical analysis, and chemicophysical research.

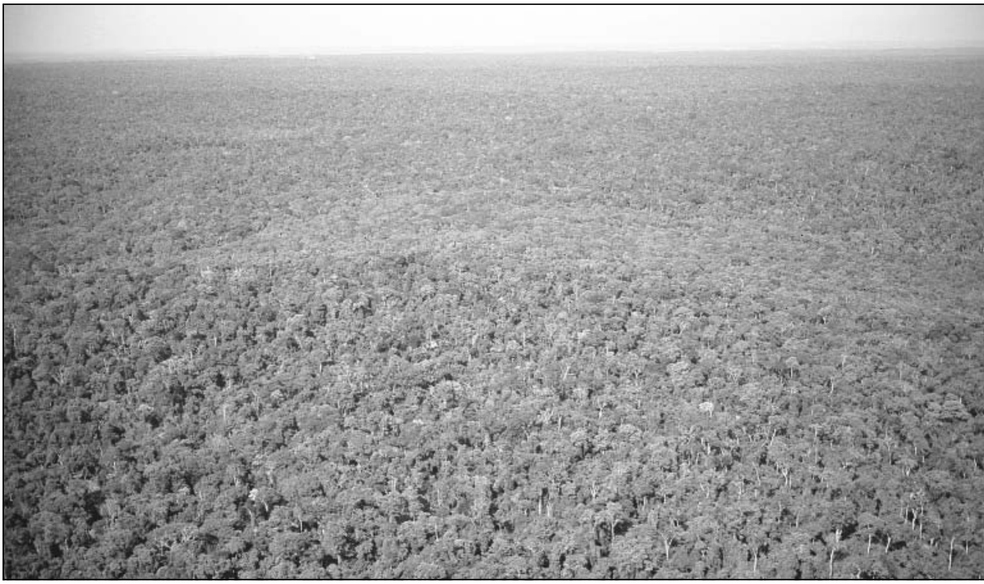
Radioactivity. ENERGY emitted spontaneously from certain types of ROCKS, through the decay of an unstable nucleus. The unstable materials that occur naturally on Earth include uranium-238, uranium-235, and thorium-232. Radioactivity has been harnessed to produce nuclear weapons and for nuclear power generation.

Radiocarbon dating. See CARBON DATING.

Radon gas. Radioactive gas and the heaviest of the noble gases. It is produced by the radioactive decay of radium, which is a natural decay product of the uranium found in various types of ROCKS. Trace amounts of radon seep from rocks and SOIL into the ATMOSPHERE and can become a health hazard in sufficient concentrations.

Rain forest. Dense evergreen FOREST with high annual RAINFALL. Most rain forests are in the TROPICS. A special rain forest is the temperate rain forest of the West Coast of the United States, where the redwoods and giant sequoias occur in small patches, now mostly protected. The tallest living trees in the world are located in this BIOME.

Most rain forests are in the Tropics; however, a special rain forest is the temperate redwood rain forest of the West Coast of the United States, where the redwoods and giant sequoias occur in small patches. (Digital Stock)



Rain forests are characterized by canopies of trees so dense that sunlight rarely reaches the ground. (PhotoDisc)

Rain forest, tropical. RAIN FOREST with monthly TEMPERATURES averaging greater than 65 DEGREES Fahrenheit (18 degrees Celsius) and monthly PRECIPITATION averaging more than 70 inches (1,800 millimeters) annually. The result is the most biologically diverse BIOME on Earth. The world's greatest expanse of tropical rain forest is in South America's Amazon Basin. Rain forests are also found in Africa, Central and South America, Asia, northern Australia, and Hawaii. Tropical rain forest covers about 7 percent of Earth's land surface, but it is being cleared at an alarming rate, especially in Brazil. This DEFORESTATION has been monitored by flights of the space shuttle and by SATELLITES. Degenerate rain forest is JUNGLE, although the two terms are often confused.

Rain gauge. Instrument for measuring RAINFALL, usually consisting of a cylindrical container open to the sky.

Rain shadow. Area of low PRECIPITATION located on the LEEWARD side of a topographic barrier such as a mountain RANGE. Moisture-laden WINDS are forced to rise, so they cool ADIABATICALLY, leading to CONDENSATION and precipitation on the WINDWARD side of the barrier. When the AIR descends on the other side of the MOUNTAIN, it is dry and relatively warm. The area to the east of the Rocky Mountains is in a rain shadow.

Rainfall. The amount of water a PLACE receives from the ATMOSPHERE over a given period. Meteorologists describe light rainfall as 0.1 inch

(2.5 millimeters) in one hour; moderate rainfall as 0.1 to 0.3 inch (2.5-7.6 millimeters) in one hour; and heavy rainfall as more than 0.3 inch (7.6 millimeters) in one hour. Climatologists are concerned with the average annual rainfall, the average over more than twenty years of rainfall records. The place with the highest annual average rainfall is Mount Waialeale, on the ISLAND of Hawaii, which receives on average 460 inches (11,700 millimeters) per year. The record for the highest rainfall in a single year belongs to Cherrapunji, in the foothills of the Himalayas, which received 1,042 inches (26,467 millimeters) in the year 1860-1861. Rainfall is measured using a RAIN GAUGE. Rainfall should not be confused with PRECIPITATION, which includes SNOW, SLEET, and hail.

Range. Difference between the highest and lowest values in a record. The TEMPERATURE range can be measured daily as the difference between the maximum and minimum temperatures, or calculated as a monthly or annual value. The TIDAL RANGE is the difference in height between the height of water at the extremes of high and low tides. This can be measured daily, or calculated for monthly or annual figures.

Range, mountain. Linear series of MOUNTAINS close together, formed in an OROGENY, or mountain-building episode. Tall mountain ranges such as the Rocky Mountains are geologically much younger than older mountain ranges such as the Appalachians.

Mountain ranges are series of mountains close together, formed in an orogeny, or mountain-building episode. (PhotoDisc)

Rank-size rule. Relationship between the POPULATION size of a CITY and its place in a hierarchy of cities within a COUNTRY. The rule is expressed mathematically—the *n*th largest city in a REGION is $1/n$ times the size of the largest city in the region. In other words, if the largest city has a population of 1 million, the fifth-largest city would have a population of one-fifth of that, or 200,000 people. The URBAN population of the United States fits the rank-size rule. The rank-size DISTRIBUTION is distorted by the presence in a country of a PRIMATE CITY, one that is disproportionally large. Mexico City, for example, is about ten times larger than Mexico's next-largest city, Guadalajara.

Rapids. Stretches of RIVERS where the water flow is swift and turbulent because of a steep and rocky CHANNEL. The turbulent conditions are called WHITE WATER. If the change in ELEVATION is greater, as for small WATERFALLS, they are called CATARACTS.

Rapids are stretches of rivers in which water flow is swift and turbulent through steep and rocky channels. (PhotoDisc)

Rational horizon. See HORIZON, TRUE.

Realm. In its older and narrowest sense, a realm is a kingdom. In its broader geographical sense, it is any political territory.

Recessional moraine. Type of TERMINAL MORAINE that marks a position of shrinkage or wasting or a GLACIER. Continued forward flow of ice is maintained so that the debris that forms the moraine continues to accumulate. Recessional moraines occur behind the terminal moraine.

Recumbent fold. Overturned fold in which the upper part of the fold is almost horizontal, lying on top of the nearest adjacent surface.

Reef (geology). VEIN of ORE, for example, a reef of gold.

Reef (marine). Underwater ridge made up of sand, rocks, or coral that rises near to the water's surface. See also CORAL REEF.

Refraction of waves. Bending of waves, which can occur in all kinds of waves. When OCEAN WAVES approach a COAST, they start to break as they approach the SHORE because the depth decreases. The wave speed is retarded and the WAVE CREST seems to bend as the wavelength decreases. If waves are approaching a coast at an oblique angle, the crest line bends near the shore until it is almost parallel. If waves are approaching a BAY, the crests are refracted to fit the curve of the bay.

Region. Area of the earth that is homogeneous in respect to certain chosen characteristics. Geographers tend to use multiple features or criteria to identify regions. CLIMATE, TOPOGRAPHY, and LANDFORMS might be used to differentiate physical regions. LANGUAGE, ethnicity, and CULTURE can be used to distinguish human regions. Industrial regions are based on their production, for example, the COTTON BELT. Regional geographers divide the world into FORMAL REGIONS, those with a measurable and usually visible homogeneity. Other regions might be defined as FUNCTIONAL REGIONS, having a definite CORE or node, such as a CITY and its HINTERLAND.

Regionalism. Feeling of collective identity by the people of a REGION, based on their personal identification with that region. Texans, for example, often display regionalism. Regionalism can influence ETHNIC GROUPS, whose aims may include increased political power or autonomy. The Basque people of the region on the west BORDER of France and Spain have created a strong regional movement, whose adherents use violent methods in their struggle for a Basque HOMELAND. The region where these feelings are expressed is a VERNACULAR REGION.

Regolith. Layer of broken ROCK at the earth's surface, lying over BEDROCK. Over time, regoliths can weather further and break down into SOIL. Regolith comprises the C horizon of a SOIL PROFILE. Slopes below CLIFFS carry a layer of regolith.

Regression. Retreat of the SEA from the land; it allows land EROSION to occur on material formerly below the sea surface.

Rejuvenation. STREAM or LANDSCAPE is rejuvenated when there is an increase in RELIEF, generally because of tectonic UPLIFT of the surface. This puts new kinetic ENERGY into the system, creating a new, lower BASE LEVEL. EROSION occurs more rapidly. LANDFORMS such as KNICKPOINTS and incised MEANDERS are evidence of rejuvenation.

Relative humidity. Measure of the HUMIDITY, or amount of moisture, in the ATMOSPHERE at any time and place compared with the total amount of moisture that same AIR could theoretically hold at that TEMPERATURE. Relative humidity is a ratio that is expressed as a percentage. When the air is saturated, the relative humidity reaches 100 percent and rain occurs. When there is little moisture in the air, the relative humidity is low, perhaps 20 percent. Relative humidity varies inversely with temperature, because warm air can hold more moisture than cooler air. Therefore, when temperatures fall overnight, the air often becomes saturated and DEW appears on grass and other surfaces. The human COMFORT INDEX is related to the relative humidity. Hot temperatures are more bearable when relative humidity is low. Media announcers frequently use the term "humidity" when they mean relative humidity.

Relative location. The location of one PLACE in relation to another place, for example, "west of the Mississippi."

Relief. In a LANDSCAPE, the difference in ELEVATION between the highest and lowest points. MOUNTAINS cut by STREAMS are areas of high relief; PLAINS are areas of low relief, although they may be at quite high elevation. A PLATEAU is a feature of high elevation but low relief.

Religion. System of belief in gods, spirits, or sacred objects. The major religions of the world are Christianity, ISLAM, Buddhism, Hinduism, and Judaism, but there are hundreds of others, as well as many branches and denominations within the major religions. Religions combine a belief system and worship with moral behavior, as well as ceremonies and institutions. Religion is an important aspect of CULTURE.

Remote sensing. Gathering information about the earth from some distance. Aerial photography and SATELLITE imagery are widely used forms of remote sensing, allowing scientists to learn much about PLACES without having to visit them in person.

Renewable resource. Renewable resources are generally living RESOURCES that can be grown and replaced; however, INSOLATION, or sunlight, is also considered an important renewable resource.

Replacement rate. The rate at which females must reproduce to maintain the size of the POPULATION. It corresponds to a FERTILITY RATE of 2.1.

Republic. System of government in which supreme power is held by representatives elected by members of the public. A republic cannot be a MONARCHY.

Reservoir. Artificial LAKE in which water is stored, for example, for IRRIGATION or for watering animals.

Reservoir rock. Geologic ROCK layer in which OIL and gas often accumulate; often SANDSTONE or LIMESTONE.

Resource. Something useful, for example, materials, services, or information. Earth scientists are often concerned with natural resources, or goods and services supplied by the natural ENVIRONMENT, as opposed to human resources, such as experience, wisdom, skill, or labor. Natural resources are generally classified as RENEWABLE and NONRENEWABLE RESOURCES. Renewable or living resources include FORESTS, plants such as grains and fruits, animals, and fish. Nonrenewable or nonliving resources include MINERALS and fuels. Humans also appreciate intangible resources, such as open space, personal satisfaction, beauty, and other abstractions. These nonmaterial resources can be economically important. Resources that are held in common, such as the OCEANS or the ATMOSPHERE, are the hardest to protect, because each individual believes his or her actions have little impact.

Respiration. Metabolic process found in animals and microbes whereby complex organic molecules (food) are oxidized to CARBON DIOXIDE, thus releasing ENERGY for work.

Retrograde orbit. ORBIT of a SATELLITE around a PLANET that is in the opposite sense (direction) in which the planet rotates.

Retrograde rotation. ROTATION of a PLANET in a direction opposite to that of its REVOLUTION.

Reverse fault. Feature produced by compression of the earth's CRUST, leading to crustal shortening. The UPTHROWN BLOCK overhangs the downthrown block, producing a FAULT SCARP where the overhang is prone to LANDSLIDES. When the movement is mostly horizontal, along a low angle FAULT, an overthrust fault is formed. This is commonly associated with extreme FOLDING.

High-angle reverse fault in Woburn, Quebec. (Geological Survey of Canada)

Reverse polarity. Orientation of the earth's MAGNETIC FIELD so that a COMPASS needle points to the SOUTHERN HEMISPHERE.

Revolution. The annual movement of the earth around the SUN in an elliptical ORBIT that takes 365.2422 DAYS.

Ria coast. Ria is a long narrow ESTUARY or RIVER MOUTH. COASTS where there are many rias show the effects of SUBMERGENCE of the land, with the SEA now occupying former RIVER VALLEYS. Generally, there are MOUNTAINS running at an angle to the coast, with river valleys between each RANGE, so that the ria coast is a succession of estuaries and promontories. The submergence can result from a rising SEA LEVEL, which is common since the melting of the PLEISTOCENE GLACIERS, or it can be the result of SUBSIDENCE of the land. There is often a great TIDAL RANGE in rias, and in some, a tidal BORE occurs with each TIDE. The eastern coast of the United States, from New York to South Carolina, is a ria coast. The southwest coast of Ireland is another. The name comes from Spain, where rias occur in the south.

Richter scale. SCALE used to measure the magnitude of EARTHQUAKES; named after American physicist Charles Richter, who, together with Beno Gutenberg, developed the scale in 1935. The scale is a quantitative measure that replaced the older MERCALLI SCALE, which was a descriptive scale. Numbers range from zero to nine, although there is no upper limit. Each whole number increase represents an order of magnitude, or an increase by a factor of ten. The actual MEASUREMENT was logarithm to base 10 of the maximum SEISMIC WAVE amplitude (in thousandths of a millimeter) recorded on a standard SEISMOGRAPH at a distance of 60 miles (100 km.) from the earthquake EPICENTER.

Ridge. Long narrow LANDFORM of high ELEVATION. The top or crest of a ridge is the ridgeline, but this is often referred to simply as a ridge. In forested REGIONS, logging roads are often constructed along ridgelines.

Rift. Portion of the earth's CRUST where TENSION has caused faulting, producing an elongate BASIN; rifts fill with SEDIMENTS and, sometimes, VOLCANIC ROCKS.

Rift propagation. Lateral movement of a rifting process that leads to the prying open of a section of the LITHOSPHERE, accompanied by the formation of IGNEOUS ROCKS.

Rift valley. Long, low REGION of the earth's surface; a VALLEY or TROUGH with FAULTS on either side. Unlike valleys produced by EROSION, rift valleys are produced by tectonic forces that have caused the faults or fractures to develop in the ROCKS of Earth's CRUST. TENSION can lead to the block of land between two faults dropping in ELEVATION compared to the surrounding blocks, thus forming the rift valley. A small LANDFORM produced in this way is called a GRABEN. A rift valley is a much larger feature. In Africa, the Great Rift Valley is partially occupied by Lake Malawi and Lake Tanganyika, as well as by the Red Sea.

Rills. Small trickles of water in a CATCHMENT area or WATERSHED. They form and enlarge through EROSION, eventually joining to form gullies.

Ring dike. Volcanic LANDFORM created when MAGMA is intruded into a series of concentric FAULTS. Later EROSION of the surrounding material may reveal the ring dike as a vertical feature of thick BASALT rising above the surroundings.

Ring of Fire. Zone of volcanic activity and associated EARTHQUAKES that marks the edges of various TECTONIC PLATES around the Pacific Ocean, especially those where SUBDUCTION is occurring.

Riparian. Term meaning related to the BANKS of a STREAM or RIVER. Riparian VEGETATION is generally trees, because of the availability of moisture.

Riparian rights. Legal regulations that allow the use of water in a STREAM by anyone who owns land through which the stream flows, provided that they do not prevent the water from continuing its downstream flow. In the United States, laws regarding riparian rights are controversial and vary from STATE to state.

River. Naturally occurring STREAM of water flowing in a natural CHANNEL. Many earth scientists, including geographers, prefer the term stream. Rivers that always contain flowing water are PERENNIAL STREAMS. Those that flow only for part of the year are INTERMITTENT STREAMS. A watercourse that has water for only a DAY or so is called an EPHEMERAL STREAM. An EXOTIC STREAM, or river, is one that flows through a DESERT, receiving its waters from some distant REGION.

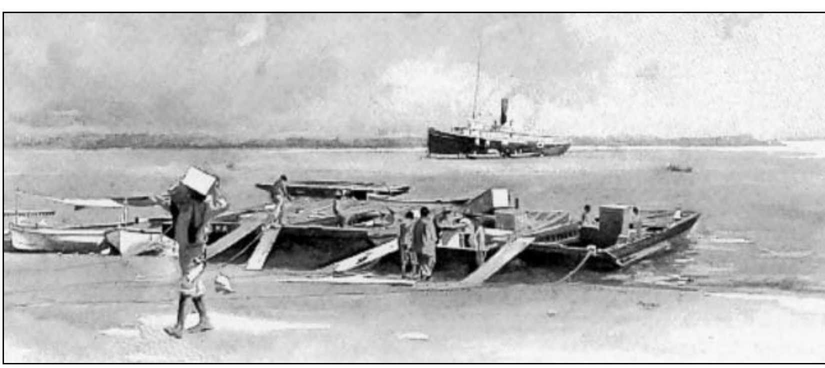
Both "river" and "stream" are used to apply to a body of water that flows in a natural channel. (PhotoDisc)

River, mouth of. See MOUTH OF RIVER.

River terraces. LANDFORMS created when a RIVER first produces a FLOODPLAIN, by DEPOSITION of ALLUVIUM over a wide area, and then begins downcutting into that alluvium toward a lower BASE LEVEL. The renewed EROSION is generally because of a fall in SEA LEVEL, but can result from tectonic UPLIFT or a change in CLIMATE pattern due to increased PRECIPITATION. On either side of the river, there is a step up from the new VALLEY to the former alluvium-covered floodplain surface, which is now one of a pair of river terraces. This process may occur more than once, creating as many as three sets of terraces. These are called depositional terraces, because the terrace is cut into river deposits. Erosional terraces, in contrast, are formed by lateral migration of a river, from one part of the valley to another, as the river creates a floodplain. These terraces are cut into BEDROCK, with only a thin layer of alluvium from the point BAR deposits, and they do not occur in matching pairs.

River valleys. VALLEYS in which STREAMS flow are produced by those streams through long-term EROSION and DEPOSITION. The LANDFORMS produced by FLUVIAL action are quite diverse, ranging from spectacular CANYONS to wide, gently sloping valleys. The patterns formed by stream networks are complex and generally reflect the BEDROCK geology and TERRAIN characteristics.

Roadstead. Coastal anchorage for ships lacking the protection of a HARBOR.



Nineteenth century roadstead harbor of Corinto, on Nicaragua's Pacific coast. (Arkent Archive)

Roches moutonnées. Erosional feature formed usually by continental GLACIATION. As an ICE SHEET advanced over a piece of resistant BEDROCK, it polished and smoothed the front side, while on the lee side PLUCKING removed sections, leading to a jagged profile. The name "rock sheep" is thought to indicate a resemblance to a sheep lying down; another explanation is that men in the nineteenth century wore wigs made of sheepskin, with the wool attached. These ROCKS look like wigs lying on a flat surface; the front is smooth, but the back is rough and curly. In English, the term "sheep rock" is sometimes used.

Rock. Naturally occurring combination of MINERALS, which make up the earth. Rocks are divided into three classes. IGNEOUS ROCKS are formed when MAGMA, or molten material, cools and solidifies. SEDIMENTARY ROCKS are formed when fragments of other rocks are cemented together. METAMORPHIC ROCKS are those that have been changed by heat and pressure; they originally may have been igneous or sedimentary.

Rock avalanche. Extreme case of a rockfall. It occurs when a large mass of ROCK moves rapidly down a steeply sloping surface, taking everything that lies in its path. It can be started by an EARTHQUAKE, rock-blasting operations, or vibrations from thunder or artillery fire.

Rock cycle. Cycle by which ROCKS are formed and reformed, changing from one type to another over long PERIODS of geologic time. IGNEOUS ROCKS are formed by cooling from molten MAGMA. Once exposed at the surface, they are subject to WEATHERING and EROSION. The products of erosion are compacted and cemented to form SEDIMENTARY ROCKS. The heat and pressure accompanying a volcanic intrusion causes adjacent rocks to be altered into METAMORPHIC ROCKS.

Rock fall. Rapid fall of blocks of ROCK. It is often the result of FROST WEDGING of rocks in an exposed CLIFF in a mountainous REGION. EARTHQUAKES can also cause rock falls.

Rock flour. Fine, powderlike material at the base of a GLACIER, produced by the constant ABRASION as the glacier and its MORAINE grind along.

Rock glacier. Form of mass movement in high MOUNTAINS that produces a lobe or tongue of broken ROCKS that moves slowly down a VALLEY. The rock is SCREE produced by FROST WEDGING. PRECIPITATION, or MELTWATER, forms an adjacent glacier and penetrates between the debris, freezing into an ice mass in the central portion. The whole mass then moves slowly downhill like a glacier. Also called a stone RIVER.

Rock salt. Sodium chloride in crystalline form. It is formed by the EVAPORATION of seawater and can be found in underground layers or beds of great thickness. Such deposits indicate the gradual evaporation of an enclosed SEA. In arid REGIONS, rock salt is obtained at the surface, through evaporation in shallow SALINE LAKES. Rock salt is mined for both domestic use and industrial purposes. In previous centuries, the need to obtain salt by mining made it an expensive commodity in Europe. SALT DOMES are an important source of rock salt. Called halite by mineralogists.

Rock slide. Event that occurs when water lubricates an unconsolidated mass of weathered ROCK on a steep slope, causing rapid downslope movement. In a RIVER VALLEY where there are steep SCREE slopes being constantly carried away by a swiftly flowing STREAM, the undercutting at the base can lead to constant rockslides of the surface layer of rock. A large rockslide is a ROCK AVALANCHE.

Ropy lava. Extremely viscous LAVA; a hot basaltic flow that cools and hardens into smooth to ropy surfaces, displaying clearly the flow lines. In Hawaii, called pahoehoe.

Lava is the magma, or molten material from within the earth, that emerges at the surface. (PhotoDisc)

Rotation. Turning of the earth on its AXIS, in an eastward, or COUNTERCLOCKWISE, direction, once every 23 hours, 56 minutes, and 4 seconds. Rotation affects the WINDS, OCEAN CURRENTS, TIDES, and length of DAY. Because of the rotation, the SUN appears to travel from east to west each day, although its position in our SOLAR SYSTEM is fixed. The rotational velocity of any point on Earth varies with its LATITUDE; a point at the EQUATOR travels at more than 1,000 miles (1,600 km.) an hour while the velocity at the POLES is zero.

Runoff. Water that becomes part of a STREAM. Water generally comes to the stream through PRECIPITATION moving as sheetflow over the land surface, or in CHANNELS such as RILLS and gullies. Also can include GROUNDWATER that flows into the stream. Total runoff is less than total precipitation for any WATERSHED, because some water is lost through EVAPORATION and some water enters the groundwater storage.

Rural. Society or SETTLEMENT in which there are a small number of inhabitants in a large area of land. AGRICULTURE is the typical economic sector. Governments classify their POPULATIONS into URBAN or rural, but the precise definition varies greatly from one COUNTRY to another. In the United States, a PLACE with more than twenty-five hundred residents is considered urban; in Japan, the urban category starts at thirty thousand.

S waves. Type of SEISMIC disturbance of the earth when an EARTHQUAKE occurs. In an S wave, particles move about at right angles to the direction in which the wave is traveling. S waves cannot pass through the earth's CORE, which is why scientists believe the INNER CORE is liquid. Also called transverse wave, shear wave, or secondary wave.

Sacred space. SITE or area recognized by certain religious groups as deserving special attention because of its connection with religious figures or religious events. Sacred sites or spaces are maintained by believers over many centuries. Pilgrims make journeys to sacred sites or spaces. The *hajj* is the pilgrimage to the sacred PLACE of Mecca that all Muslims must try to make once in their lifetime. Lourdes in France is a sacred space visited by hundreds of thousands of Roman Catholic pilgrims each year.

Saddle. See COL.

Sahel. Southern edge of the Sahara Desert; a great stretch of semiarid land extending from the Atlantic Ocean in Senegal and Mauritania through Mali, Burkina Faso, Nigeria, Niger, Chad, and Sudan. Northern Ethiopia, Eritrea, Djibouti, and Somalia usually are included also. This transition zone between the hot DESERT and the tropical SAVANNA has low summer RAINFALL of less than 8 inches (200 millimeters) and a natural VEGETATION of low grasses with some small shrubs. The REGION traditionally has been used for PASTORALISM, raising goats, camels, and occasionally sheep. Since a prolonged DROUGHT in the 1970's, DESERTification, soil EROSION, and FAMINE have plagued the Sahel. The narrow band between the northern Sahara and the Mediterranean North African COAST is also called Sahel. "Sahel" is the Arabic word for edge.

Salina. See ALKALI FLAT.

Saline lake. LAKE with elevated levels of dissolved solids, primarily resulting from evaporative concentration of SALTS; saline lakes lack an out-

California's Mono Lake is an interesting example of a naturally saline lake whose chemical salt concentrations have risen even higher because of human intervention. (PhotoDisc) let to the SEA. Well-known examples include Utah's Great Salt Lake, California's Mono Lake and Salton Sea, and the Dead Sea in the Middle East.

Salinity. Measure of the concentration of dissolved SALTS in seawater. Salinity is the amount of salt in grams dissolved in one kilogram of seawater. The value is written in parts per thousand. Average salinity of the OCEANS is 35 parts per thousand.

Salinization. Accumulation of SALT in SOIL. When IRRIGATION is used to grow crops in semiarid to arid REGIONS, salinization is frequently a problem. Because EVAPORATION is high, water is drawn upward through the soil, depositing dissolved salts at or near the surface. Over years, salinization can build up until the soil is no longer suitable for AGRICULTURE. The solution is to maintain a plentiful flow of water while ensuring that the water flows through the soil and is drained away.

Salt. In chemistry, a substance formed when an acid reacts with a base. In everyday terms, salt refers to sodium chloride or table salt, which is the most common form of salt.

Salt domes. Formations created when deeply buried salt layers are forced upwards. SALT under pressure is a plastic material, one that can flow or move slowly upward, because it is lighter than surrounding SEDIMENTARY ROCKS. The salt forms into a plug more than a half mile (1 km.) wide and as much as 5 miles (8 km.) deep, which passes through overlying sedimentary rock layers, pushing them up into a dome shape as it passes. Some salt domes emerge at the earth's surface; others are close to the surface and are easy to mine for ROCK SALT. OIL and NATURAL GAS often accumulate against the walls of a salt dome. Salt domes are numerous around the COAST of the Gulf of Mexico, in the North Sea REGION, and in Iran and Iraq, all of which are major oil-producing regions.

Salt water. Water with a SALT content of 3.5 percent, such as is found in normal OCEAN water.

Saltation. Process whereby a particle is moved forward by water or WIND, being lifted, carried, and then dropped, over and over. It comes from the Latin word for "jump" and has nothing to do with table SALT.

Saltwater intrusion. AQUIFER contamination by salty waters that have migrated from deeper aquifers or from the SEA.

Saltwater lake. See SALINE LAKE.

Saltwater wedge. Wedge-shaped intrusion of seawater from the OCEAN into the bottom of a RIVER; the thin end points upstream.

Sand. Grain or particle size with a diameter ranging between 0.0008 inch (0.02 millimeter) for fine sand to 0.08 inch (2 millimeters) for coarse sand. Sand can be many colors. Most sand is composed mostly of QUARTZ and is formed by EROSION of granitic ROCKS. The resulting quartz sand is yellowish. BASALT weathers into black sand. Coral forms white or occasionally pink sand.

Sand dunes. Accumulations of SAND in the shape of mounds or RIDGES. They occur on some COASTS and in arid REGIONS. Coastal dunes are formed when the prevailing WINDS blow strongly onshore, piling up sand into dunes, which may become stabilized when grasses grow on them. DESERT sand dunes are a product of DEFLATION, or wind EROSION removing fine materials to leave a DESERT PAVEMENT in one region and sand deposits in another. Sand dunes are classified by their shape into barchans, or crescent-shaped dunes; seifs or LONGITUDINAL DUNES; TRANSVERSE DUNES; star dunes; and sand drifts or sand sheets.

Sand spit. See SPIT.

Sandbar. When BEACH SAND is moved by WAVES and LONGSHORE CURRENTS, it can form long narrow deposits called BARS. They are named according to their position. An offshore bar is parallel to the COAST. A baymouth bar encloses a BAY, running from one HEADLAND to the other. A bar extending outward from the land at one end is a SPIT; a connecting bar is known as a TOMBOLO. Bars are unstable and temporary LANDSCAPE features. Along the southern and eastern coasts of the United States are huge sandbars called BARRIER ISLANDS.

Red sandstone formation near Arbroath, Scotland. Historically, this sandstone was used both for building and for ballast in ships. (Ray Sumner)

Sandstone. Common SEDIMENTARY ROCK produced through the LITHIFICATION of sand-sized grains. The pore spaces between the grains may be empty, filled with AIR, or filled with a cementing material such as calcium carbonate.

Sapping. Natural process of EROSION at the bases of HILL slopes or CLIFFS whereby support is removed by undercutting, thereby allowing overlying layers to collapse; SPRING SAPPING is the facilitation of this process by concentrated GROUNDWATER flow, generally at the heads of VALLEYS.

Satellite. Small object that revolves around a larger object. The MOON is a natural satellite of Earth. In this SOLAR SYSTEM, only Mercury and Venus have no satellites. Humans have also created many artificial satellites, the first of these being Sputnik 1, launched on October 4, 1957, by the Soviet Union. Hundreds of satellites now ORBIT Earth. Satellites are used for COMMUNICATIONS, military purposes, and scientific research, such as WEATHER FORECASTING and studying VEGETATION, OCEANS, and atmospheric changes. The GLOBAL POSITIONING SYSTEM (GPS) uses signals from satellites to accurately obtain ABSOLUTE LOCATIONS on Earth. This military application was developed by the United States in the late 1970's and made available to the public in the 1990's. Geographers make wide use of imagery from the series of satellites named LANDSAT (also Earth Resources Technology Satellite) and a series of satellites named GOES (Geostationary Operational Environmental Satellite). This type of research is called REMOTE SENSING.

Satellite meteorology. Study of atmospheric phenomena using SATELLITE data; an indispensable tool for forecasting WEATHER and studying CLIMATE on a global scale.

Saturation, zone of. Underground REGION below the zone of AERATION, where all pore space is filled with water. This water is called GROUNDWATER; the upper surface of the zone of saturation is the WATER TABLE.

Savanna. VEGETATION that consists of tall grass with occasional trees and shrubs interspersed. Savanna occurs in the TROPICS, between the tropical RAIN FOREST and the semiarid REGIONS that fringe true DESERTS. The CLIMATE is tropical with rain concentrated in the summer months, followed by a long dry season. In some countries, people divide the climate of these areas into two SEASONS—wet and dry—because in the Tropics, TEMPERATURES are high all year. Because the rain falls in summer, much moisture is lost through EVAPORATION, so moisture conditions are insufficient for FOREST growth. Trees are scarce and small to medium in height, with small leaves, spreading crowns, and an extensive root system. SOILS of the savanna are more fertile than those of the tropical rain forest, and some farming is undertaken in these areas, especially if water for IRRIGATION is available. Savannas cover about 40 percent of the earth's lands. They are thought to have been extended through the human practice of setting fire to the dry grasses at the end of the dry season in order to ensure fresh new growth when the rains came; therefore, many plants of the savanna are fire tolerant. The savanna BIOME is particularly extensive in Africa. In South America, the savanna of Venezuela is called LLANOS; it is called Campo Cerrado or Pantanal in different parts of Brazil. Savanna also occurs in India, Madagascar, and Thailand. The name is sometimes spelled savannah. See also GRASSLAND.

Scale. Relationship between a distance on a MAP or diagram and the same distance on the earth. Scale can be represented in three ways. A linear, or graphic, scale uses a straight line, marked off in equally spaced intervals, to show how much of the map represents a mile or a kilometer. A representative fraction (RF) gives this scale as a ratio. A verbal scale uses words to explain the relationship between map size and actual size. For example, the RF 1:63,360 is the same as saying "one inch to the mile."

Scarp. Short version of the word "ESCARPMENT," a short steep slope, as at the edge of a PLATEAU. EARTHQUAKES lead to the formation of FAULT SCARPS.

Schist. METAMORPHIC ROCK that can be split easily into layers. Schist is commonly produced from the action of heat and pressure on SHALE or SLATE. The rock looks flaky in appearance. Mica-schists are shiny because of the development of visible mica. Other schists include talc-schist, which contains a large amount of talc, and hornblende-schist, which develops from basaltic rocks.

Scree. Broken, loose ROCK material at the base of a slope or CLIFF. It is often the result of FROST WEDGING of BEDROCK cliffs, causing rockfall. Another name for scree is TALUS.

Sea. Part of an OCEAN that is partially enclosed by land. Seas occur at the margins of oceans. Well-known seas include the Caribbean, Mediterranean, Red, Black, and North. There is no clear distinction in naming water features, however. For example, the Bay of Bengal might be termed a sea. On the other hand, some saltwater LAKES are misnamed seas. Examples are the Caspian Sea, Aral Sea, and Dead Sea. These are all lakes, because they are totally landlocked and are not part of a larger ocean.

Sea fog. See ADVECTION FOG.

Sea level. Standard reference height, which is used as a basis for all ELEVATIONS above or below for terrestrial or submarine elevations, respectively. The height of the sea-land interface is constantly changing, mainly because of the EBB and flow of TIDES. CURRENTS, WINDS, pressure conditions, and other factors also have an effect. When an elevation is given as a height above sea level, this refers to a height above MEAN SEA LEVEL. Mean sea level (MSL) is calculated from average hourly tidal records over many years. For the United States, records are assembled for more than forty tidal gauges, together with data from the TOPEX Poseidon SATELLITE. The MSL of the Gulf of Mexico is higher than the MSL of the Atlantic COAST. Florida has the lowest MSL in the United States; Oregon has the highest. Sea levels have changed throughout the earth's history. Since the last ICE AGE, around fifteen thousand years ago, sea level has risen because of the melting ice. On average, the increase in sea level is about 400 feet (130 meters). The prediction that GLOBAL WARMING will cause a rise in sea level in the near future is a cause of concern, because so many people throughout the world live close to the coast. A rise of only 1 foot (0.3

meter) would destroy billions of dollars worth of valuable real estate, inundate rich farmlands, and completely cover the HOMELANDS of some ISLAND NATIONS in the Pacific and Indian Oceans.

Sea lane. See SEAWAY.

Seafloor spreading. Term often used to refer to the separation of the OCEAN floor at a spreading center located along a MID-OCEAN RIDGE. The theory was advanced in the 1960's, and new evidence over the following decades confirmed the hypothesis. Seafloor spreading occurs where TECTONIC PLATES are diverging, or moving apart, and new CRUST is being created. Volcanic ERUPTIONS, fractures, and EARTHQUAKES accompany seafloor spreading. The spreading is balanced by SUBDUCTION, when plates converge and crust is destroyed.

Seamount. Large VOLCANO rising more than 3,000 feet (1,000 km.) from the OCEAN floor to near the surface. LAVA erupts from a fracture or RIFT on the ocean floor. Oceanographic research has shown that there are twenty thousand seamounts in the world oceans. A seamount with a flat top is called a GUYOT; these features are important to the explanation of CORAL REEFS and ATOLLS throughout the Pacific Ocean.

Seasons. An Earth year is conventionally divided into four seasons—spring, summer, autumn or fall, and winter. The division into seasons is based on TEMPERATURE changes, which are related to changes in the length of DAY. This is caused by the tilt of the earth's AXIS at 23.5 DEGREES from vertical, which means that the CIRCLE OF ILLUMINATION changes in the course of a year as the earth revolves around the SUN. In North America, the seasons are said to start at the summer SOLSTICE, the autumnal EQUINOX, the WINTER SOLSTICE, and the VERNAL or spring equinox. In the SOUTHERN HEMISPHERE, the pattern of seasons is reversed, so that summer in the NORTHERN HEMISPHERE corresponds to winter in the Southern Hemisphere. In polar REGIONS, seasons are extreme, with darkness throughout the winter and daylight throughout the summer. At the EQUATOR, the opposite holds; there is no variation in daylength throughout the year. Countries that experience the MONSOON, especially India and Southeast Asia, experience only three seasons—hot-wet, cool-dry, and hot-dry.

Seaway. Route traveled by ships on the open SEAS. Often the word is used to refer to the actual passage by the ship. In large seas, a ship makes a heavy seaway. A seaway is also a large CANAL constructed to provide interior access for large oceangoing ships, such as the Saint Lawrence Seaway, which connects North America's Great Lakes to the Atlantic Ocean by way of the Gulf of Saint Lawrence. Also called a sea lane.

Secondary industry. That part of the ECONOMY that takes the raw materials produced by the primary sector of the economy and processes them into salable products. At a simple level, this might be the milling of grain into flour, or the sawing of logs into lumber. Secondary industry also involves heavy and technically sophisticated industries such as steel production, shipbuilding, and automobile manufacture. Some economists distinguish between light industry and heavy industry.

Secondary waves. See S WAVES.

Sectionalism. Form of extreme devotion to local interests and customs.

Sediment. Solid earth material that has been weathered and is deposited after being transported by water, ice, or WIND, or moved downward by GRAVITY. Sedimentation refers to the laying down of deposits that, after consolidation or cementation, become SEDIMENTARY ROCKS.

Light-colored sediment from the Mississippi River flowing into the Gulf of Mexico. (U.S. Geological Survey)

Sedimentary rocks. ROCKS formed from SEDIMENTS that are compressed and cemented together in a process called LITHIFICATION. Sedimentary rocks cover two-thirds of the earth's land surface but are only a small proportion of the earth's CRUST. SANDSTONE is a common sedimentary rock. Sedimentary rocks form STRATA, or layers, and sometimes contain FOSSILS.

Segregation. Spatial separation of a subgroup of a POPULATION, often because of discrimination. Ethnic ENCLAVES are a largely voluntary form of segregation, because the residents have a close sense of community and internal cohesion. An extreme example of such segregation is called a ghetto. Apartheid was a form of segregation in South Africa based on racial discrimination, the separation of white and non-white—largely black—populations.

Seif dunes. Long, narrow RIDGES of SAND, built up by WINDS blowing at different times of year from two different directions. Seif dunes occur in parallel lines of sand over large areas, running for hundreds of miles in the Sahara, Iran, and central Australia. Another name for seif dunes is LONGITUDINAL DUNES. The Arabic word means sword.

Seismic. Pertaining to EARTHQUAKES.

Seismic activity. Movements within the earth's CRUST that often cause various other geological phenomena to occur; the activity is measured by SEISMOGRAPHS.

Seismic belt. REGION of relatively high SEISMICITY, globally distributed; seismic BELTS mark regions of PLATE interactions.

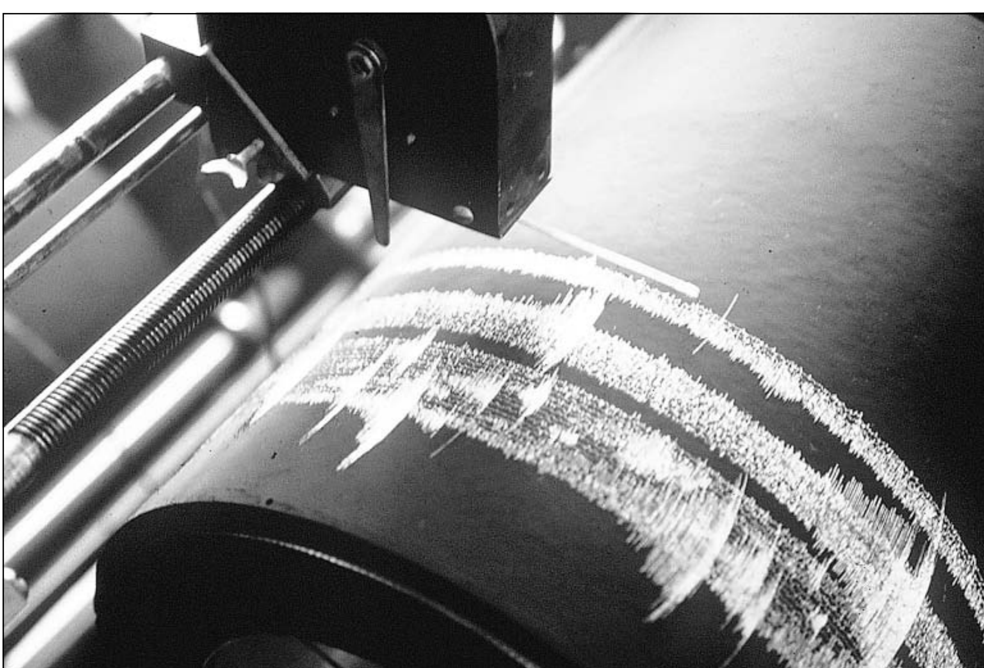
Seismic gap. FAULT REGION known to have had previous EARTHQUAKES but not within the area's most recent recurrence period.

Seismic wave. TSUNAMI or an OCEAN WAVE caused by a seismic event under the ocean.

Seismicity. Occurrence of EARTHQUAKES, which is expressed as a function of LOCATION and time.

Seismogram. Image of EARTHQUAKE wave vibrations recorded on paper, photographic film, or a video screen.

Seismograph. Instrument used to record the ground shaking that occurs with an EARTHQUAKE. In a simple seismograph, a paper is attached to a



Smoke-drum seismographic record. (U.S. Geological Survey) rotating drum, and a pen is attached to an arm that is firmly embedded in the ground, so that it vibrates when the earth moves. Seismographs also record earth movements caused by atomic explosions.

Seismology. The scientific study of EARTHQUAKES. It is a branch of GEOPHYSICS. The study of SEISMIC WAVES has provided a great deal of knowledge about the composition of the earth's interior.

Seismometer. Instrument that measures the motion of the ground, used to record SEISMIC ENERGY; also known as a geophone or a seismic detector.

Self-determination. Right of a group of people who occupy a distinct territory to control that territory and determine their own future development or destiny. The Palestinians have fought both physically and politically for the right to control their own territory, or STATE, and thus to enjoy the benefits of self-determination.

Semidesert. REGION with DESERT characteristics but with greater PRECIPITATION than a true desert.

Service sector. See TERTIARY INDUSTRY.

Settlement. Small community of people and their residences. A settlement is smaller than a TOWN, so settlements are generally found in RURAL areas. Cultural geographers study settlement patterns. Clustered settlements, where the houses are relatively close together, are common in Europe and Asia; dispersed settlements are more common in rural parts of North America, in Australia, and in Africa.

Shadow zone. When an EARTHQUAKE occurs at one LOCATION, its waves travel through the earth and are detected by SEISMOGRAPHS around the world. Every earthquake has a shadow zone, a band where neither P nor S WAVES from the earthquake will be detected. This shadow zone leads scientists to draw conclusions about the size, density, and composition of the earth's CORE.

Shale. SEDIMENTARY ROCK consisting of layers of fine-grained materials of CLAY or SILT size. Shale is the most abundant of the sedimentary rocks. It is a raw material for brick making and ceramics.

Shale oil. SEDIMENTARY ROCK containing sufficient amounts of hydrocarbons that can be extracted by slow distillation to yield OIL.

Shallow-focus earthquakes. EARTHQUAKES having a focus less than 35 miles (60 km.) below the surface.

Shantytown. URBAN SQUATTER SETTLEMENT, usually housing poor newcomers.

Shear waves. See S WAVES.

Sheet erosion. See SHEET WASH.

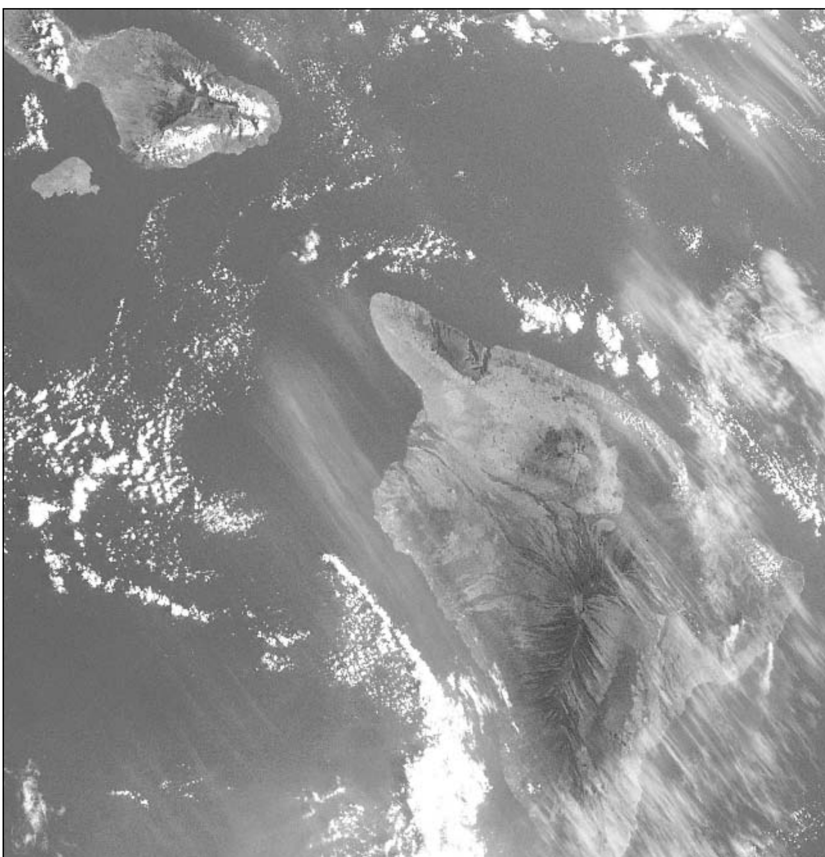
Sheet wash. When water flows as a thin sheet across a slope, it can erode loose materials such as SOIL particles that previously were dislodged by SPLASH EROSION. This generally occurs after a sudden and intense period of PRECIPITATION. It can lead to considerable loss of TOPSOIL on an unplanted field. Sheet wash can also occur on BEDROCK surfaces. In nature, sheet wash is less common than channeled flow, where the rainwater gathers into RILLS; in URBAN AREAS, however, sheet wash can be seen on streets during a rainstorm as water flows toward storm drains. Also called sheet erosion.

Sheikdom. Islamic COUNTRY whose ruler bears the title of *sheik*.

Shelter belt. Another word for a WINDBREAK.

Shield. Large part of the earth's CONTINENTAL CRUST, comprising very old ROCKS that have been eroded to REGIONS of low RELIEF. Each CONTINENT has a shield area. In North America, the Canadian Shield extends from north of the Great Lakes to the Arctic Ocean. Sometimes known as a CONTINENTAL SHIELD.

Shield volcano. VOLCANO created when the LAVA is quite viscous or fluid and highly basaltic. Such lava spreads out in a thin sheet of great radius



The Hawaiian Islands contain some of the greatest shield volcanoes on earth. Several of those volcanoes can be seen in this 1988 satellite photograph of Maui (left) and Hawaii (right). (Corbis) but comparatively low height. As flows continue to build up the volcano, a low DOME shape is created. The greatest shield volcanoes on Earth are the ISLANDS of Hawaii, which rise to a height of almost 30,000 feet (10,000 meters) above SEA LEVEL.

Shire. English COUNTY.

Shoal. Underwater RIDGE or sandbed that reduces the water's depth to a point that might be unsafe for vessels.

Shock city. CITY that typifies disturbing changes in social and cultural conditions or in economic conditions. In the nineteenth century, the shock city of the United States was Chicago.

Shore. The zone where land and SEA meet. It extends from the water's edge at the lowest TIDE to the farthest point inland where SAND has been deposited by the largest STORM WAVES.

Shoreline. The specific PLACE where the land meets the SEA. Since WAVES and TIDES change constantly, the shoreline is not a fixed LOCATION. The position of MEAN SEA LEVEL is based on calculations of records of shoreline height.

Sial. Acronym for *si*lica and *al*umina. Those are the two principal constituents of light and crystalline ROCKS, such as GRANITE, that make up the greater part of the earth's CONTINENTAL CRUST. Heavier, basaltic rocks are referred to as SIMA.

Sierra. Spanish word for a mountain RANGE with a serrated crest. In California, the Sierra Nevada is an important range, containing Mount Whitney, the highest PEAK in the continental United States.

Silica. Oxide of silicon, with the chemical formula SiO_2. Silica occurs as QUARTZ or as part of many other ROCKS, including GRANITE. Silica is the most abundant oxide on Earth, and quartz is the second-most abundant MINERAL, after FELDSPAR.

Sill. Feature formed by INTRUSIVE volcanic activity. When LAVA is forced between two layers of ROCK, it can form a narrow horizontal layer of BASALT, parallel with the adjacent beds. Although it resembles a windowsill in its flatness, a sill may be hundreds of miles long and can range in thickness from a few centimeters to considerable thickness.

Silt. Intermediate TEXTURE size, for SOIL particles or for SEDIMENT, between SAND and CLAY. Silt particles have a diameter of 0.00016 to 0.0024 inch (0.004-0.06 millimeter). Silt is carried in SUSPENSION by RIVERS, giving them an opaque appearance, with color ranging from reddish to yellowish to brown-gray, depending on the MINERAL content of the silt. Silt can also be blown by WINDS. When it is deposited in thick layers, it is called LOESS.

Siltation. Build-up of SILT and SAND in creeks and waterways as a result of SOIL EROSION, clogging water courses and creating DELTAS at RIVER MOUTHS. Siltation often results from DEFORESTATION or removal of tree cover. Such ENVIRONMENTAL DEGRADATION causes loss of agricultural productivity, worsening of water supply, and other problems.

Sima. Acronym for *si*lica and *ma*gnesium. These are the two principal constituents of heavy ROCKS such as BASALT, which forms much of the OCEAN floor. Lighter, more abundant rock is SIAL.

Simple crater. Small IMPACT CRATER with a simple bowl shape.

Sinkhole. Circular depression in the ground surface, caused by WEATHERING of LIMESTONE, mainly through the effects of SOLUTION on JOINTS in the ROCK. If a STREAM flows above ground and then disappears down a sinkhole, the feature is called a swallow hole. In everyday language, many events that cause the surface to collapse are called sinkholes, even though they are rarely in limestone and rarely caused by weathering.

This sinkhole, which appeared in central Alabama in 1972, was 350 feet (105 meters) wide and 150 feet (45 meters) deep. (U.S. Geological Survey)

Sinking stream. STREAM OR RIVER that loses part or all of its water to pathways dissolved underground in the BEDROCK.

Site. Locational attributes of a TOWN OR CITY, its physical setting as well as its layout. In earlier times, a site was often chosen for its defensive property, so hilltops, or ISLANDS in RIVERS, became the sites of SETTLEMENTS.

Situation. Relationship between a PLACE, such as a TOWN OR CITY, and its RELATIVE LOCATION within a REGION. A situation on the COAST is desirable in terms of overseas TRADE.

Slate is a metamorphic rock that can be split into thin sheets. (PhotoDisc)

Slate. METAMORPHIC ROCK that has a unique ability to be split into thin sheets; some slates are resistant to WEATHERING and are thus good for exterior use.

Sleet. Transparent drops of ice, caused by the freezing of raindrops. A TEMPERATURE INVERSION with below-freezing temperatures near the earth surface is a common cause of sleet. Sometimes, a mixture of SNOW and rain is incorrectly referred to as sleet.

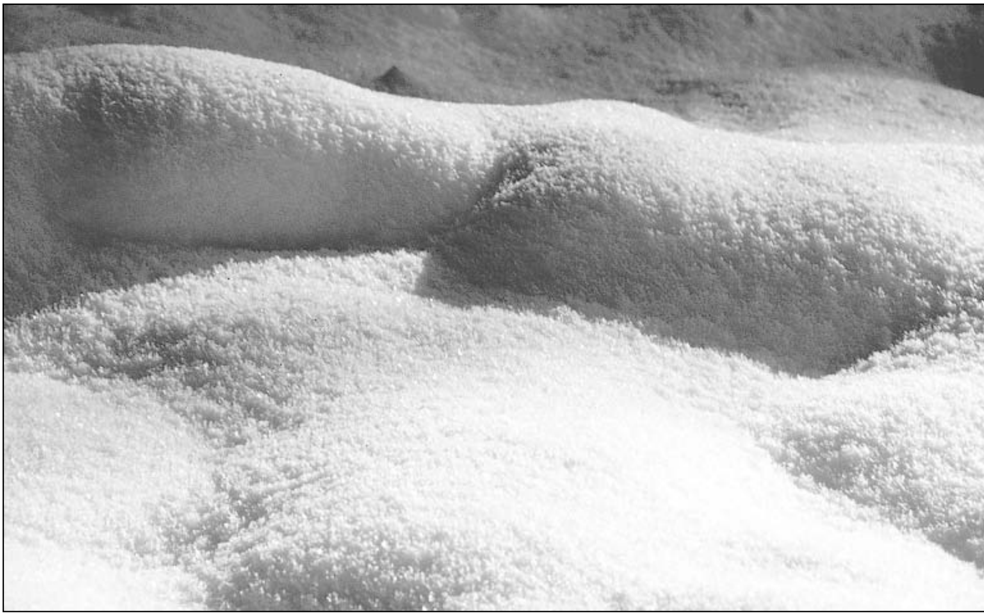
Slip-face. LEEWARD side of a SAND DUNE. As the WIND piles up sand on the WINDWARD side, it then slips down the rear or slip-face. The angle of the slip-face is gentler than the angle of the windward slope.

Slough. Depression of the earth's surface containing a small amount of water and mud; a kind of MARSH or BOG.

Slump. Type of LANDSLIDE in which the material moves downslope with a rotational motion, along a curved slip surface.

Smog. Composite word formed from *sm*oke and f*og*. It was originally coined to describe the foul combination in London in the nineteenth century, when COAL fires were heavily used to heat homes and power factories. Sulfur dioxide, produced by burning coal, emitted sulfuric acid into the moist ATMOSPHERE. This true fog is also called industrial smog, to distinguish it from PHOTOCHEMICAL SMOG, which is a misnomer, because it involves no smoke.

Snout. Terminal end of a GLACIER.



Snow is frozen water in a crystalline form. More than one-fifth of the earth's land surface is covered in snow or ice. (PhotoDisc)

Snow. Frozen water in a crystalline form. Snowflakes have a hexagonal shape and form at high ALTITUDES around tiny nuclei such as DUST particles. More than one-fifth of the earth's land surface is covered in snow or ice.

Snow line. The height or ELEVATION at which snow remains throughout the year, without melting away. Near the EQUATOR, the snow line is more than 15,000 feet (almost 5,000 meters); at higher LATITUDES, the snow line is correspondingly lower, reaching SEA LEVEL at the POLES. The actual snow line varies with the time of year, retreating in summer and coming lower in winter.

Social Darwinism. Application of the ideas of Charles Darwin to human societies. Darwin thought that animal organisms or species evolved as the result of the struggle to survive in their physical ENVIRONMENT; social Darwinists believe that human groups also struggle to survive in particular environments. Cultural groups thus evolved through their ability to adjust and adapt to their physical environment. These ideas are closely related to the theory of ENVIRONMENTAL DETERMINISM.

Soil. The fine, natural material covering most of the earth's land surface, in which plants grow. Soil is formed by the physical and CHEMICAL WEATHERING of ROCK. Organisms ranging from bacteria and algae to worms, insects, and rodents make their home in soil. Soil is a mixture of MINERALS and organic matter, containing both water and AIR. As the basis of plant life, soil supports all terrestrial life on Earth. Soils take thousands of years to form but can be degraded or eroded rapidly, so soil conservation is a major area of concern throughout the world.

Soil horizon. SOIL consists of a series of layers called horizons. The uppermost layer, the O horizon, contains organic materials such as decayed leaves that have been changed into HUMUS. Beneath this is the A horizon, the TOPSOIL, where farmers plow and plant seeds. The B HORIZON often contains MINERALS that have been washed downwards from the A horizon, such as calcium, iron, and aluminum. The A and B horizons together comprise a solum, or true soil. The C horizon is weathered BEDROCK, which contains pieces of the original ROCK from which the soil formed. Another name for the C horizon is REGOLITH. Beneath this is the R horizon, or bedrock.

Soil moisture. Water contained in the unsaturated zone above the WATER TABLE.

Soil profile. Vertical section of a SOIL, extending through its horizon into the unweathered parent material.

Soil stabilization. Engineering measures designed to minimize the opportunity and/or ability of EXPANSIVE SOILS to shrink and swell.

Solar constant. Average value for the INSOLATION received at the THERMOPAUSE, or outer limit of the earth's ATMOSPHERE. The solar constant is 1,372 watts per square meter (2 calories per square centimeter per minute, or 2 langleys per minute).

Solar eclipse. See ECLIPSE, SOLAR.

Solar energy. One of the forms of ALTERNATIVE OR RENEWABLE ENERGY. In the late 1990's, the world's largest solar power generating plant was located at Kramer Junction, California. There, solar energy heats huge OIL-filled containers with a parabolic shape, which produces steam to drive generating turbines. An alternative is the production of energy through photovoltaic cells, a TECHNOLOGY that was first developed for space exploration. Many individual homes, especially in isolated areas, use this technology.

Solar nebula. Disk-shaped cloud of hot DUST and gas from which the SOLAR SYSTEM formed.

Solar radiation. Transfer of heat from the SUN to the earth's surface, where it is absorbed and stored. See also INSOLATION.

Solar system. SUN and all the bodies that ORBIT it, including the PLANETS and their SATELLITES, plus numerous COMETS, ASTEROIDS, and METEOROIDS.

Solar wind. Gases from the SUN'S ATMOSPHERE, expanding at high speeds as streams of charged particles.

Solifluction. Word meaning flowing SOIL. In some REGIONS of PERMAFROST, where the ground is permanently frozen, the uppermost layer thaws during the summer, creating a saturated layer of soil and REGOLITH above the hard layer of frozen ground. On slopes, the material

Solifluction lobes on the side of a kame in the Nunatarssuaq region of Greenland. (U.S. Geological Survey)

can flow slowly downhill, creating a wavy appearance along the hillslope.

Solstices. Dates on which the SUN's rays at noon are vertically above the tropics, which are at their SUBSOLAR POINTS. The WINTER SOLSTICE in the NORTHERN HEMISPHERE occurs on December 21 or 22; this is the shortest DAY of the year in that HEMISPHERE. The summer solstice in the Northern Hemisphere occurs on June 20 or 21. The subsolar point then is the tropic of CANCER, and this is the longest day of the year for the Northern Hemisphere. In the SOUTHERN HEMISPHERE, the solstices occur on the same day, but the SEASONS are reversed: winter begins on the June solstice and summer begins on the December solstice.

Solution. Form of CHEMICAL WEATHERING in which MINERALS in a ROCK are dissolved in water. Most substances are soluble, but the combination of water with CARBON DIOXIDE from the ATMOSPHERE means that RAINFALL is slightly acidic, so that the chemical reaction is often a combination of solution and carbonation.

Sound. Long expanse of the SEA, close to the COAST, such as a large ESTUARY. It can also be the expanse of sea between the mainland and an ISLAND.

Source rock. ROCK unit or bed that contains sufficient organic carbon and has the proper thermal history to generate OIL or gas.

Southern Hemisphere. The half of the earth below the EQUATOR.

Southern Oscillation. Atmospheric "seesaw" that tilts between ATMOSPHERIC PRESSURE extremes at Tahiti and Darwin, Australia.

Sovereignty. Exercise of government and STATE power over people and the territory they occupy. Sovereignty is recognized by other sovereign states and is upheld by international law. The individual states of the United States, the PROVINCES of Canada, and the counties of the United Kingdom are administrative subdivisions of these independent countries. These smaller entities do not have sovereignty.

Spa. PLACE with natural MINERAL SPRINGS.

Spatial diffusion. Notion that things spread through space and over time. An understanding of geographic change depends on this concept. Spatial diffusion can occur in various ways. Geographers distinguish between expansion diffusion, relocation diffusion, and hierarchical diffusion.

Spheroidal weathering. Form of ROCK WEATHERING in which layers of rock break off parallel to the surface, producing a rounded shape. It results from a combination of physical and CHEMICAL WEATHERING. Spheroidal weathering is especially common in GRANITE, leading to the creation of TORS and similar rounded features. Onion-skin weathering is a term sometimes used, especially when this is seen on small rocks.

Spillway. Generally, a broad reinforced CHANNEL near the top of the DAM, designed to allow rising waters to escape the RESERVOIR without overtopping the dam.

Spit. Long, narrow sandbar extending outward from the COAST. A sand spit is attached to the coast at one end. Cape Cod is a famous spit. See also HOOK.

Barrier sand spit along the South Carolina coast. (U.S. Geological Survey)

Splash erosion. EROSION that occurs when raindrops hit the ground, dislodging particles of SOIL or weathered material and causing them to move downslope. Splash erosion can lead to OVERLAND FLOW, which can cause considerable erosion of newly plowed ground.

Spread effects. Positive impacts on economic growth throughout a REGION. Economic growth in a center or region is usually accompanied by spread effects. For example, the effect of providing work and income leads to an increased demand for housing, food, entertainment, and other consumer goods, thereby creating further employment and growth.

Spring. PLACE where water flows naturally from the ground, found wherever the WATER TABLE intersects the earth's surface; in KARST TOPOGRAPHY, a spring represents the discharge point of a CAVE.

Spring sapping. Process in which water flows out of subsurface SPRINGS to surface level, forming a STREAMBED as it flows downslope.

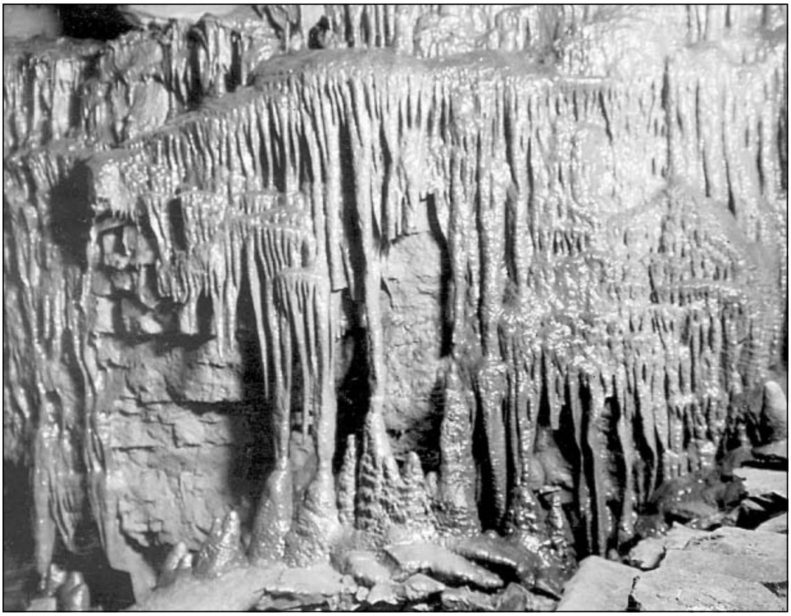
Spring tide. TIDE of maximum RANGE, occurring when lunar and solar tides reinforce each other, a few DAYS after the full and new MOONS.

Squall line. Line of vigorous THUNDERSTORMS created by a cold downdraft that spreads out ahead of a fast-moving COLD FRONT.

Squatter settlements. URBAN residential slums built by recent urban immigrants on land that they do not own or rent. Shacks in the squatter settlements are built of found materials, including cardboard, mud, grass, and plastic sheeting. These squatter settlements are known by different names in different countries: "favelas" in Brazil, "callampas" in Chile, "villas miserias" in Argentina, "bustees" in India, and "gourbevilles" or "bidonvilles" in parts of Africa. Governments often supply water and power to squatter settlements, and residents may form communities to improve the structures and services. Also called informal settlements.

Stacks. Pieces of ROCK surrounded by SEA water, which were once part of the mainland. WAVE EROSION has caused them to be isolated. Also called sea stacks.

Sea stacks. (Corbis)



Stalactites (above) and stalagmites (below) that have grown together in Kentucky's Mammoth Cave National Park. (U.S. Geological Survey)

Stalactite. Long, tapering piece of calcium carbonate hanging from the roof of a LIMESTONE CAVE or cavern. Stalactites are formed as water containing the MINERAL in solution drips downward. The water evaporates, depositing the dissolved minerals. See also STALAGMITE.

Stalagmite. Column of calcium carbonate growing upward from the floor of a LIMESTONE CAVE or cavern. See also STALACTITE.

State. Territory and its political organization, with administration regulated by a government with sovereign powers, and that is recognized as legitimate by other states that are members of the international community of legitimate states. The international BORDERS of the state must be agreed upon by adjacent states and by other states. A state has a citizen POPULATION resident within its territory and an organized and functioning ECONOMY. In the United States, "state" is also the term used for a subdivision of the whole; in other countries, such an internal administrative REGION is called a PROVINCE, department, or other name.

Steppe. Huge REGION of GRASSLANDS in the midlatitudes of Eurasia, extending from central Europe to northeast China. The region is not uniform in ELEVATION; most of it is rolling PLAINS, but some mountain RANGES also occur. These have not been a barrier to the migratory lifestyle of the herders who have occupied the steppe for many centuries. The Asian steppe is colder than the European steppe, because of greater elevation and greater continentality. The best-known rulers from the steppe were the Mongols, whose empire flourished in the thirteenth and fourteenth centuries. Geographers speak of a steppe

CLIMATE, a semiarid climate where the EVAPORATION rate is double that of PRECIPITATION. South of the steppe are great DESERTS; to the north are midlatitude mixed FORESTS. In terms of climate and VEGETATION, the steppe is like the short-grass PRAIRIE vegetation west of the Mississippi River. Also called steppes.

Stock. Feature formed by INTRUSIVE volcanic activity. LAVA rises toward the surface and forms a mass or POOL that slowly cools into a granitic ROCK LANDFORM, often circular in shape. Removal of the overlying materials can subsequently expose the stock as a HILL. A much larger feature formed in the same manner is a BATHOLITH.

Stone river. See ROCK GLACIER.

Storm. Atmospheric disturbance with rotating WINDS of considerable speed, associated with lower-than-usual pressure. CLOUDS, PRECIPITATION, and often thunder and LIGHTNING accompany the passage of a storm. Storms can be classified as HURRICANES, TORNADOES, or low-pressure systems.

Storm clouds forming over the Grand Tetons in Wyoming. (PhotoDisc)

Storm surge. General rise above normal water level, resulting from a HURRICANE or other severe coastal STORM.

Strait. Relatively narrow body of water, part of an OCEAN or SEA, separating two pieces of land. The world's busiest SEAWAY is the Johore Strait between the Malay Peninsula and the island of Sumatra.

Strata. Layers of SEDIMENT deposited at different times, and therefore of different composition and TEXTURE. When the sediments are laid down, strata are horizontal, but subsequent tectonic processes can

Folds in strata at the southern end of Montana's Scapegoat Mountain. (U.S. Geological Survey)

lead to tilting, FOLDING, or faulting. Not all SEDIMENTARY ROCKS are stratified. Singular form of the word is stratum.

Strategic resources. RESOURCES considered essential for a NATION's major industries, military defense, and ENERGY programs. For the United States, these resources include manganese, chromium, cobalt, nickel, platinum, titanium, aluminum, and OIL.

Stratified drift. Material deposited by glacial MELTWATERS; the water separates the material according to size, creating layers.

Stratigraphic time scale. History of the evolution of life on the earth broken down into time periods based on changes in FOSSIL life in the sequence of ROCK layers; the time periods were named for the localities in which they were studied or from their characteristics.

Stratigraphic unit. Any ROCK layer that can be easily recognized because of specific characteristics, such as color, composition, or grain size.

Stratigraphy. Study of sedimentary STRATA, which includes the concept of time, possible correlation of the ROCK units, and characteristics of the rocks themselves.

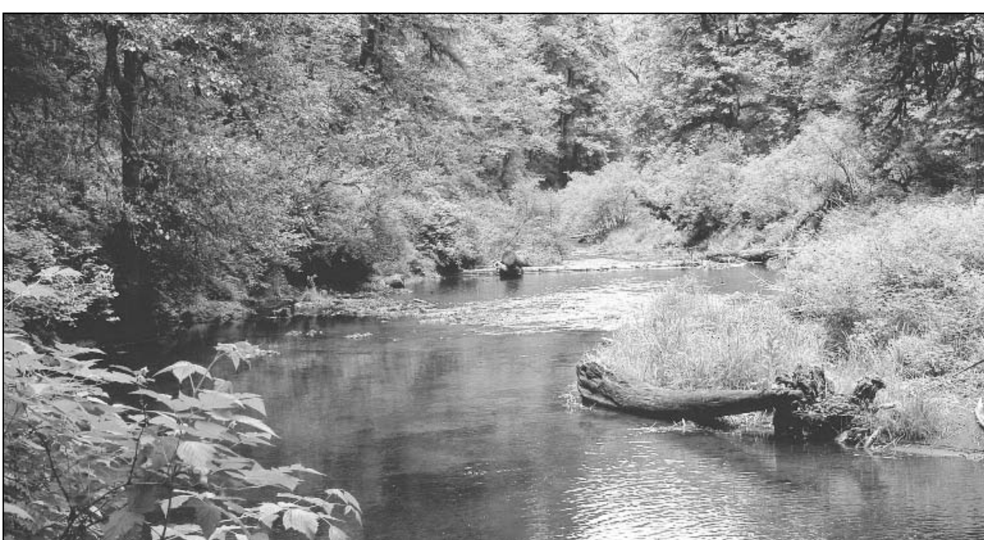
Stratosphere. Layer of the ATMOSPHERE distinguished by a rise in TEMPERATURE from bottom to top. This warming mainly results from absorption of SOLAR RADIATION by OZONE molecules found in the stratosphere. The stratosphere extends from about 11 miles (17 km.) above the earth's surface to about 30 miles (50 km.) in ALTITUDE. Below the stratosphere is the TROPOSPHERE; above it is the MESOSPHERE.

Mount Rainier, an ancient stratovolcano, one whose eruptions are of different types and produce different lavas. (Corbis)

Stratovolcano. Type of VOLCANO in which the ERUPTIONS are of different types and produce different LAVAS. Sometimes an eruption ejects cinder and ASH; at other times, viscous lava flows down the sides. The materials flow, settle, and fall to produce a beautiful symmetrical LANDFORM with a broad circular base and concave slopes tapering upward to a small circular CRATER. Mount Rainier, Mount Saint Helens, and Mount Fuji are stratovolcanoes. Also known as a COMPOSITE CONE.

Stratum. A single bed or layer of SEDIMENTARY ROCK. See also STRATA.

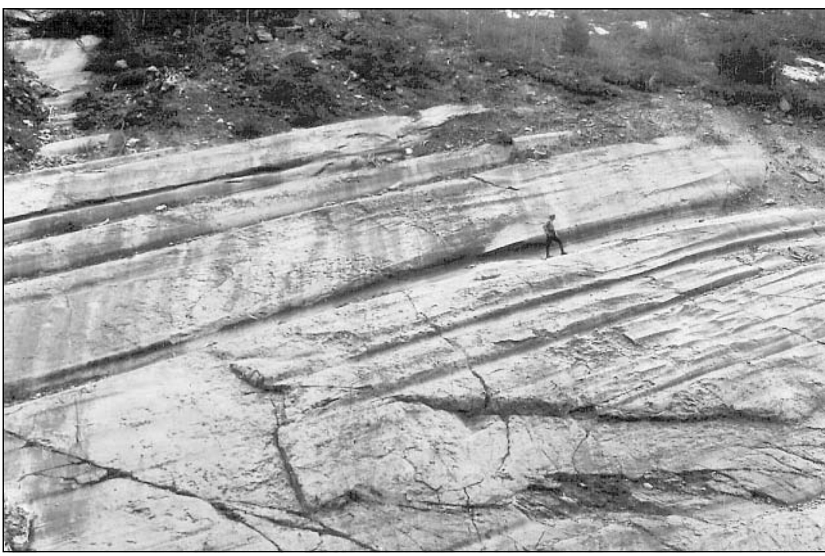
Stream. Body of water in a CHANNEL, moving downhill because of GRAVITY. Geographers prefer the term to "river," because it emphasizes the fact



Geographers and other physical scientists tend to prefer the word "stream" over "river" for a body of water that moves down a channel. (PhotoDisc) that water flows in a confined channel, between BANKS. "River" is a less precise term, partly because it suggests a large and constant stream. In arid REGIONS, streams are often INTERMITTENT in their flow, or even EPHEMERAL, when they contain flowing water only for a short period.

Stream order. System of studying STREAMS devised by Robert Horton, an American hydrologist. The smallest streams in the HEADWATERS are designated first-order streams. When two first-order streams converge, the result is a second-order stream. When two second-order streams converge, a third-order stream is formed. Quantifying a DRAINAGE network in this way enables calculations of drainage area, discharge, and other factors in the stream network.

Streambed. Channel through which a STREAM flows. Dry streambeds are variously known as ARROYOS, DONGAS, WASHES, and WADIS.



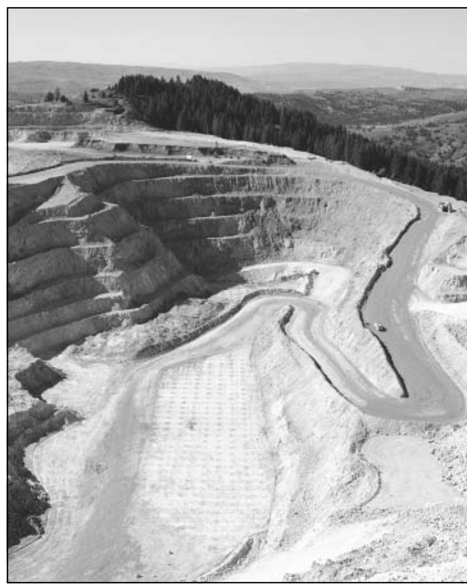
Striations cut into Devonian-era dolomite by large, sharp rocks pushed by glacial ice. (U.S. Geological Survey)

Striations. Grooves eroded into BEDROCK by the ground MORAINE, or ROCKS, carried by a GLACIER as it makes its way downslope. Sometimes the striations are merely scratches; in other places the grooves can be several centimeters deep. Study of striations now exposed reveals much about the direction and size of glacial flows during previous ICE AGES.

Strike. Term used when earth scientists study tilted or inclined beds of SEDIMENTARY ROCK. The strike of the inclined bed is the direction of a horizontal line along a bedding plane. The strike is at right angles to the dip of the rocks.

Strike-slip fault. In a strike-slip fault, the surface on either side of the fault moves in a horizontal plane. There is no vertical displacement to form a FAULT SCARP, as there is with other types of faults. The San Andreas Fault is a strike-slip fault. Also called a transcurrent fault.

Strip mining. Removal of a long narrow strip of surface materials, using excavation machinery called a dragline. The underlying MINERAL deposit then can be collected easily. When the dragline moves across to the adjacent land to excavate the next strip, parallel to the first, the waste or overburden from the former strip is deposited back over that strip of land. COAL deposits are often mined using strip mining. This type of mining is destructive of natural ENVIRONMENTS.



Strip mining involves the removal of long narrow strips of surface materials, using excavation equipment called draglines, so that underlying minerals can be collected easily. (PhotoDisc)

Subcontinent. Large piece of a CONTINENT. The term is especially used when referring to the Indian subcontinent.

Subduction. Process that occurs when two TECTONIC PLATES converge. If one plate is composed of lighter CONTINENTAL CRUST and the other of heavier OCEANIC CRUST, the lighter plate rides up over the heavier plate, forcing it downward. This is a destructive process, destroying crust. At PLATE BOUNDARIES where subduction is occurring, oceanic TRENCHES are found close to the SHORE, with tall, young MOUNTAINS close to the COAST on the land. Active VOLCANOES are common, and ERUPTIONS and EARTHQUAKES are frequent. The combination of the Peru Trench and the Andes Mountains marks a large plate boundary REGION where subduction is proceeding.

Subduction zone. CONVERGENT PLATE BOUNDARY where an oceanic PLATE is being thrust below another plate.

Sublimation. Process by which water changes directly from solid (ice) to vapor, or vapor to solid, without passing through a liquid stage.

Submarine canyon. CHANNEL cut deep in the seafloor SEDIMENTS by RIVERS or submarine CURRENTS.

Submergence. COASTLINE of submergence is formed when SEA LEVELS that have risen since the last ICE AGE have made former RIVER VALLEYS and other LANDFORMS INLETS, estuaries, and BAYS.

Subsidence. Sinking of the earth's surface or a decrease in the distance between the earth's surface and its center.

Subsistence agriculture. System of production in which farmers grow only enough food to feed themselves and their immediate families, with just enough seed left over to ensure a crop the following year. No surplus is produced for sale. Shifting cultivation is a form of subsistence agriculture. Subsistence agriculturalists usually produce a variety of crops throughout the year and may keep a few animals for food. The opposite of subsistence agriculture is commercial agriculture.

Subsoil. Term for the C horizon in a soil. See also SOIL.

Subsolar point. Point on the earth's surface where the SUN is directly overhead, making the Sun's rays perpendicular to the surface. The subsolar point receives maximum INSOLATION, compared with other PLACES, where the Sun's rays are oblique.

Suburbanization. Growth of POPULATION around the edge or fringe of a CITY. This process of city growth began in the United States in the eighteenth century, when wealthy people moved out of the crowded, unhealthful city to the RURAL edge where they could have a large property with fresh AIR and a large garden. This led to recent immigrants moving into the inner city.

Sultanate. Islamic STATE ruled by a person with the title of sultan.

Summer solstice. See SOLSTICES.

Summit. Highest part of any LANDFORM remnant, HILL, PEAK, or MOUNTAIN. A summit can be either smooth or sharply defined.

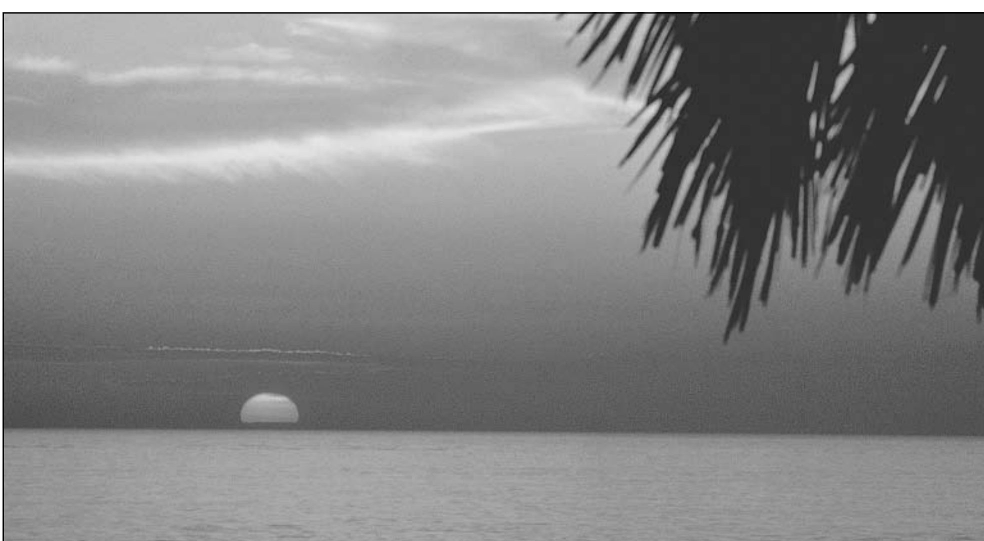
Sun. The center of Earth's SOLAR SYSTEM, the Sun is an average star in terms of its physical characteristics. It is a large sphere of incandescent gas that has a diameter more than 100 times that of Earth, a mass more than 300,000 times that of Earth, and a volume 1.3 million times that of Earth. The Sun's surface GRAVITY is thirty-four times that of Earth. The earth revolves around the Sun in a slightly elliptical ORBIT that takes exactly one Earth year to complete.

Sun Belt. Name given to certain parts of the United States that attract IMMIGRATION because of their warm sunny CLIMATES. Retired people are the main component of Sun Belt MIGRATION. The Sun Belt is not a continuous BELT, but California, Texas, Florida, Nevada, and New Mexico have benefited from this trend.

Sunrise occurs when the top of the Sun first appears above the horizon. As with sunsets, these times vary with location and season. (PhotoDisc)

Sunrise. The time when the top of the SUN first appears above the HORIZON. This time changes throughout the year.

Sunset. The time when the last part of the SUN totally disappears below the HORIZON. This time changes throughout the year.



Sunset is the moment when the last part of the Sun disappears below the horizon. The exact times vary within individual time zones and change throughout the year, with the changes becoming greater with distance away from the equator. (PhotoDisc)

Sunspots. Regions of intense magnetic disturbances that appear as dark spots on the solar surface; they occur approximately every eleven years.

Supercontinent. Vast landmass of the remote geologic past formed by the collision and amalgamation of crustal plates. Hypothesized supercontinents include Pangaea, Gondwanaland, and Laurasia.

Supersaturation. State in which the air's relative humidity exceeds 100 percent, the condition necessary for vapor to begin transformation to a liquid state.

Supranationalism. Process by which autonomous countries join together in an agreement for their mutual benefit. Supranational ventures usually are economic in nature; the North American Free Trade Agreement is an example of supranationalism between the United States, Canada, and Mexico. Supranationalism can also be cultural or military, for example the North Atlantic Treaty Organization.

Supratidal. Referring to the shore area marginal to shallow oceans that are just above high-tide level.

Surface water. Relatively warm seawater between the ocean surface and that depth marked by a rapid reduction in temperature.

Suspension. Means by which small particles are moved by water or wind. The particles are so light that they can be picked up and transported. Suspended particles make rivers appear muddy, or make dust clouds visible.

Sustainable agriculture. Commercial agriculture that is ecologically responsible and sound. Soil conservation is practiced, using contouring and shallow plowing. Pest management is achieved by intercropping or natural pesticides, rather than chemicals.

Sustainable energy. See Alternative energy.

Swamp. Wetland where trees grow in wet to waterlogged conditions. Swamps are common close to the river on floodplains, as well as in some coastal areas.

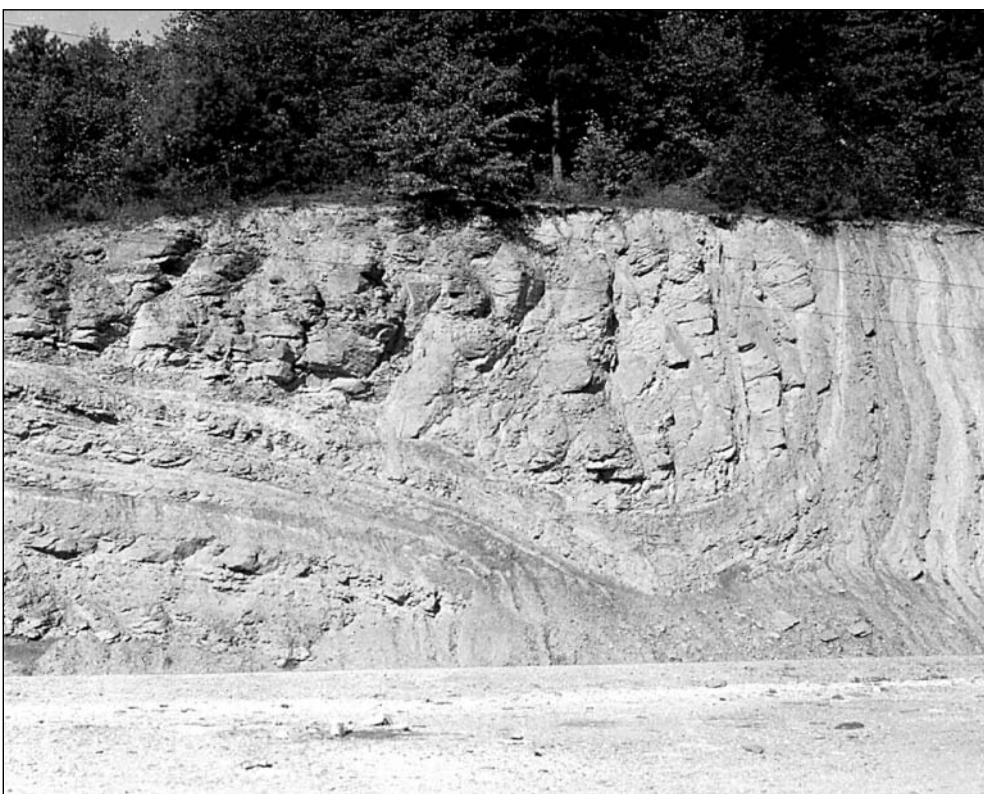
Swell. Regular pattern of smooth rounded waves moving across the ocean surface in one direction.

Swidden. Area of land that has been cleared for subsistence agriculture by a farmer using the technique of slash-and-burn. A variety of crops is planted, partly to reduce the risk of crop failure. Yields are low from a swidden because soil fertility is low and only human labor is used for clearing, planting, and harvesting. See also Intertillage.

Symbiosis. Cooperative living arrangement of two different species. When both species benefit, it is called mutualism; when one benefits more than the other, it is called commensalism. Parasitism sometimes is regarded as a form of symbiosis.

Symbolic landscapes. Landscapes centered on buildings or structures that are so visually emblematic that they represent an entire city. The Eiffel Tower of Paris or the Harbour Bridge of Sydney are examples of such features. Other cities have more generic cityscapes that are symbolic of the entire NATION or the entire CULTURE. For the United States, three such symbolic cityscapes are recognized by most geographers. The New England VILLAGE or townscape, with the steepled white wooden church and village green, accompanied by DECIDUOUS trees in fall colors, not only represents a regional architecture but also symbolizes a community rooted in Puritan values of morality, industriousness, and a God-centered, family-oriented life. The familiar symbolic cityscape generally referred to as Main Street U.S.A. is an image of an earlier age, with sidewalks and small, family-run shops, which was adopted as the centerpiece of Disneyland. The California landscape is a third symbolic U.S. landscape, typified by tall palms, suburban houses, and an individualistic, recreation-oriented, middle-class POPULATION. This final landscape has been widely popularized by the motion picture industry.

Syncline. Downfold or TROUGH shape that is formed through compression of ROCKS. An upfold is an ANTICLINE.



Syncline in weathered shale, with a left limb that dips to the right and a vertical right limb. (U.S. Geological Survey)

Cape Town's aptly named Table Mountain, viewed from Table Bay in South Africa. (Corbis)

Table mountain. MESA with a particularly well-defined shape resembling a table. The most famous MOUNTAIN of this type is Cape Town's aptly named Table Mountain in South Africa.

Tableland. Large area of land with a mostly flat surface, surrounded by steeply sloping sides, or ESCARPMENTS. A small PLATEAU.

Taiga. Russian name for the vast BOREAL FORESTS that cover Siberia. The marshy ground supports a tree VEGETATION in which the trees are CONIFEROUS, comprising mostly pine, fir, and larch.

Takeoff. Stage in the economic DEVELOPMENT of a COUNTRY when conditions are right for the country to undergo an industrial revolution, making that country an industrialized export ECONOMY. The term comes from the work of the American economist Walter Rostow.

Talus. Broken and jagged pieces of ROCK, produced by WEATHERING of steep slopes, that fall to the base of the slope and accumulate as a talus cone. In high MOUNTAINS, a ROCK GLACIER may form in the talus. See also SCREE.

Tarn. Small circular LAKE, formed in a CIRQUE, which was previously occupied by a GLACIER.

Taxonomy. Another name for a system of scientific classification. The SOIL classification used in the United States is called the Soil Taxonomy or the Seventh Approximation.

Technology. Practical application of knowledge. It could refer to simple techniques such as using fire to cook food or a ROCK to crack oysters. In modern use, technology implies the use of power and machinery, as in mining technology or COMMUNICATIONS technology. In developed or high-income economies, technology has largely replaced the need for human labor, but many low-income countries have a low level of technology.

Tectonic plate. Large portion of the earth's CRUST. Plates are in constant motion, separating or colliding, changing the shape of CONTINENTS and the configuration of the surface both above and below SEA LEVEL. The North American Plate is slowly moving northwest. The other large plates are the South American, African, Eurasian, Indo-Australian, and ANTARCTIC plates. There are also several smaller plates.

Tectonism. The formation of MOUNTAINS because of the deformation of the CRUST of the earth on a large scale.

Temperate zone. Areas between the tropic of CANCER and the Arctic Circle and between the tropic of CAPRICORN and the Antarctic Circle. The ancient Greeks divided the world into three CLIMATE zones, based on their understanding of geometry and geography. At the EQUATOR was the hot REGION the Greeks called the Torrid Zone, believing that human life was not possible there. At the POLES were the two FRIGID ZONES, thought to be too cold for human life. Between the Torrid and Frigid Zones lay two temperate zones, one in each HEMISPHERE. The civilized world as known to the ancient Greeks lay in the temperate zone, where humans flourished because AGRICULTURE was possible. Although the Greeks believed that life was possible in the temperate zone of the SOUTHERN HEMISPHERE, they did not think that the beings there would resemble the humans of the NORTHERN HEMISPHERE. Because the Greeks thought it was not possible to travel through the Torrid Zone to see what the southern regions were like, there were speculations about whether the inhabitants there had one eye, or perhaps walked upside down, because of the earth's curvature. Drawings of creatures with feet on their heads led to the origin of the word ANTIPODES, which is now used to described southern lands.

Temperature. Measure of the kinetic ENERGY of molecules, felt by humans as sensible heat. Temperature is usually measured using the CELSIUS SCALE, but in the United States, the FAHRENHEIT SCALE is more commonly used. The Kelvin scale is used by scientists.

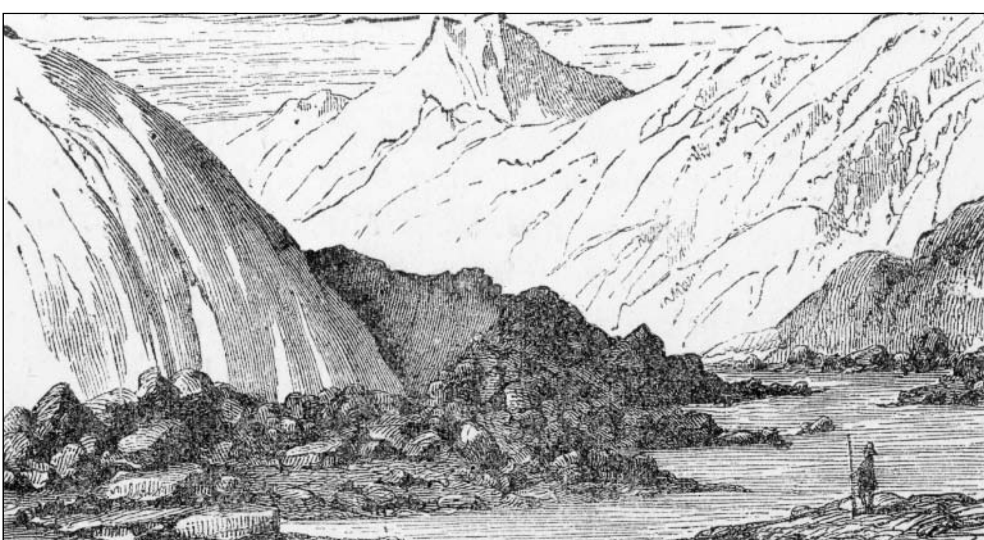
Temperature inversion. Increase in AIR TEMPERATURE with increased ALTITUDE. This is the opposite of normal conditions whereby the temperature in the TROPOSPHERE decreases uniformly with height. An inversion can be produced in a number of ways. A RADIATION or ground inversion occurs on cold clear nights when the ground cools rapidly through terrestrial radiation. Air in contact with this cold surface is then cooled, becoming colder than the air above it. If the air is moist and the temperature falls below the DEW POINT, FOG can form; this is called a radiation fog. A SUBSIDENCE inversion forms when air in a high-pressure cell descends and unequal compression causes the upper part of the air to become warmer than the lower part. An inversion can form in the surface layer or at an upper level in the troposphere. A layer of stratus CLOUDS usually marks the upper-level inversion. TOPOGRAPHY can be an important influence on a ground inversion. In hilly or mountainous areas, cold air drains into the VALLEYS, especially at night, and causes an inversion that can persist for more than one DAY. Under normal conditions, warm air near the surface rises because it is less dense, which lessens POLLUTION. Cool surface air overlain with warmer air prevents the upward rise of smoke and other pollutants, which become trapped under the inversion layer. The United States' worst AIR POLLUTION disaster occurred in Donora, Pennsylvania, in 1948, when a temperature inversion led to a deadly fog full of industrial pollutants; it persisted for four days, affecting thousands of people and causing twenty deaths.

Temporary base level. STREAMS OR RIVERS erode their beds down toward a BASE LEVEL—in most cases, SEA LEVEL. A section of hard ROCK may slow EROSION and act as a temporary, or local, base level. Erosion slows upstream of the temporary base level. A DAM is an artificially constructed temporary base level.

Tension. Type of stress that produces a stretching and thinning or pulling apart of the earth's CRUST. If the surface breaks, a NORMAL FAULT is created, with one side of the surface higher than the other.

Tephra. General term for volcanic materials that are ejected from a vent during an ERUPTION and transported through the AIR, including ASH (volcanic), BLOCKS (volcanic), cinders, LAPILLI, scoria, and PUMICE.

Terminal moraine. RIDGE of unsorted debris deposited by a GLACIER. When a glacier erodes it moves downslope, carrying ROCK debris and



Terminal moraine in the French Alps. (Mark Twain, *A Tramp Abroad*, 1880) creating a ground MORAINE of material of various sizes, ranging from big angular blocks or boulders down to fine CLAY. At the terminus of the glacier, where the ice is melting, the ground moraine is deposited, building the ridge of unsorted debris called a terminal moraine.

Terra rossa. Red SOIL formed from LIMESTONE, which provides a strong contrast to the paler limestone BEDROCK below. The red color comes from insoluble iron hydroxides. Name is Italian for red soil.

Terrace. Horizontal RIDGE in a hillside. In many Asian countries, the steep slopes of HILLS or mountainsides have been transformed, through great human effort, into a series of steplike terraces to provide flat land for rice PADDIES. RIVER TERRACES are natural formations on either side of a RIVER.

Asian rice paddies maximizing agriculture use of difficult mountainous terrain. (PhotoDisc)

Terracettes. Small parallel TERRACES or steps on a hillslope. They are thought to originate from a combination of mass movement downslope and trampling by the hooves of grazing animals.

Terrain. Physical features of a REGION, as in a description of rugged terrain. It should not be confused with TERRANE.

Terrane. Piece of CONTINENTAL CRUST that has broken off from one PLATE and subsequently been joined to a different plate. The terrane has quite different composition and structure from the adjacent continental materials. Alaska is composed mostly of terranes that have accreted, or joined, the North American plate.

Terrestrial planet. Any of the solid, rocky-surfaced bodies of the inner SOLAR SYSTEM, including the PLANETS Mercury, Venus, Earth, and Mars and Earth's SATELLITE, the MOON.

Terrigenous. Originating from the WEATHERING and EROSION of MOUNTAINS and other land formations.

Tertiary industry. Sector of the ECONOMY, also known as the service sector, that does not produce material goods for sale. Tertiary industry includes services such as banking and insurance, real estate, retailing, TRANSPORTATION and COMMUNICATIONS, and such necessities as police, defense, and education. In high-income economies, most people are employed in the tertiary sector; the secondary sector is of diminished importance, and primary industries are highly mechanized, with few workers.

Tertiary period. PERIOD in the CENOZOIC ERA of the geologic time scale; it encompasses the time span between about 65 million and 2 million years ago.

Texture. One of the properties of SOILS. The three textures are SAND, SILT, and CLAY. Texture is measured by shaking the dried soil through a series of sieves with mesh of reducing diameters. A mixture of sand, silt, and clay gives a LOAM soil.

Thalweg. Profile obtained when the ELEVATION of a STREAMBED is plotted against the STREAM's length. The shape is a concave curve. German word for "valley way" or "path," spelled *Talweg* in modern German.

Thematic map. MAP that displays information concerning a theme, such as geology, VEGETATION, or annual PRECIPITATION. Using computer mapping with a Geographic Information System (GIS), many themes can be added to a project, overlaid to create spatial queries, and displayed as desired.

Thermal equator. Imaginary line connecting all PLACES on Earth with the highest mean daily TEMPERATURE. The thermal equator moves south of the EQUATOR in the SOUTHERN HEMISPHERE summer, especially over the CONTINENTS of South America, Africa, and Australia. In the northern summer, the thermal equator moves far into Asia, northern Africa, and North America.

Thermal erosion. EROSION of water ice from a solid state to vapor.

Thermal fracture. Formation of a fracture or crack in a ROCK as a result of TEMPERATURE changes.

Thermal gradient. Increase of TEMPERATURE with depth below the earth's surface, expressed as DEGREES Celsius per kilometer; the average is 25 to 30 degrees Celsius per kilometer; also known as GEOTHERMAL gradient.

Thermal pollution. Disruption of the ECOSYSTEM caused when hot water is discharged, usually as a thermal PLUME, into a relatively cooler body of water. The TEMPERATURE change affects the aquatic ecosystem, even if the water is chemically pure. Nuclear power-generating plants use large volumes of water in the process and are important sources of thermal pollution.

Thermal springs. See HOT SPRINGS.

Thermocline. Depth interval at which the TEMPERATURE of OCEAN water changes abruptly, separating warm SURFACE WATER from cold, deep water.

Thermodynamics. Area of science that deals with the transformation of ENERGY and the laws that govern these changes; equilibrium thermodynamics is especially concerned with the reversible conversion of heat into other forms of energy.

Thermometer. Instrument for measuring TEMPERATURE. Commonly, a long thin glass tube containing alcohol. Early thermometers used mercury in a glass tube. The liquid inside the tube expands when the temperature rises. There are three temperature SCALES in regular use: CELSIUS, FAHRENHEIT, and Kelvin. Most countries in the world use the Celsius scale, where the boiling point of pure water is 100 DEGREES and the freezing point is zero. Temperatures in the United States are usually given in degrees Fahrenheit. On this scale, the temperature at which water boils is 212 degrees, and the temperature at which water freezes is 32 degrees.

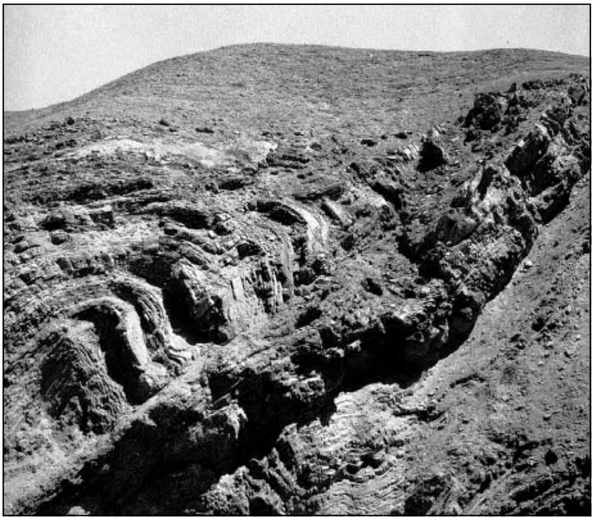
Thermopause. Outer limit of the earth's ATMOSPHERE.

Thermosphere. Atmospheric zone beyond the MESOSPHERE in which TEMPERATURE rises rapidly with increasing distance from the earth's surface.

Third World. Term formerly used to refer to low-income countries, where the standard of living was poor and per-capita income low. The term dates from the COLD WAR, when the capitalist countries were regarded as the First World, and the Communist countries as the Second World.

Threshold. Minimum market size required to make the sale of a product, or the provision of a service, economically profitable. Luxury goods may need few buyers and so they have a low threshold; fast-food outlets need to sell large quantities of their product, so they have a high threshold. See also RANGE.

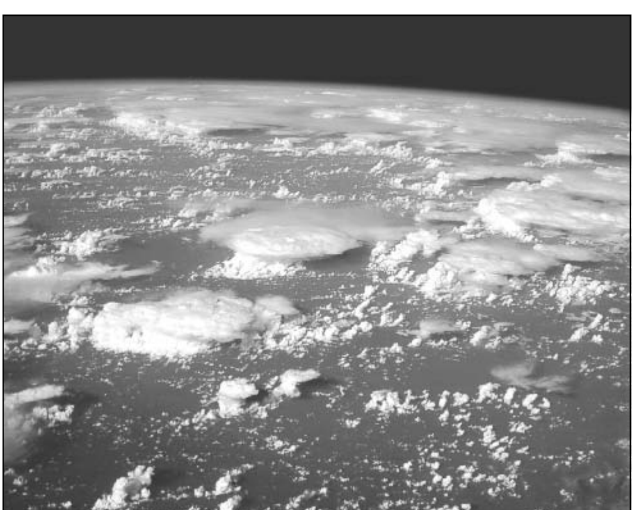
Thrust belt. Linear BELT of ROCKS that have been deformed by THRUST FAULTS.



Thrust fault showing fault drag. (U.S. Geological Survey)

Thrust fault. FAULT formed when extreme compression of the earth's CRUST pushes the surface into folds so closely spaced that they overturn and the ROCK then fractures along a fault.

Thunderstorm. Huge CUMULONIMBUS CLOUD that brings heavy rain, or sometimes hail, together with thunder and LIGHTNING. CUMULUS clouds form in moist warm AIR as it rises, and the presence of updrafts can lead to continued growth of the clouds into a thunderhead. Such clouds typically have a flat top, or anvil head, when they reach their greatest height of development, which may be in the STRATOSPHERE. A TORNADO can develop from a thunderstorm. MICROBURSTS are another common phenomenon.



Cumulus clouds form in moist warm air as it rises, and the presence of updrafts can lead to continued growth of the clouds into thunderheads, which typically have flat tops, or anvil heads, when they reach their greatest elevations, which may be in the stratosphere. (Corbis)

Tidal bore. See BORE.

Tidal energy. The regular EBB and flow of TIDES can be harnessed, in suitable LOCATIONS such as narrow INLETS or estuaries where there is a large TIDAL RANGE, and used to generate electricity. The oldest tidal generating plant is located at La Rance in France; another is located in the Bay of Fundy in Nova Scotia.

Tidal force. Gravitational force whose strength and direction vary over a body and thus act to deform the body.

Tidal range. Difference in height between high TIDE and low tide at a given point.

Tidal wave. Common but inaccurate name for a TSUNAMI.

Tides. Daily variations in SEA LEVEL, and in large LAKES, caused by the gravitational pull of the MOON and SUN on the earth, and especially on the HYDROSPHERE. When Earth, Moon, and Sun are in conjunction (lined up), it causes SPRING TIDES with the greatest TIDAL RANGE (highest and lowest tides). When the three bodies are in opposition (aligned at right angles), it causes NEAP TIDES, those in which the tidal range is smallest. Most COASTS on Earth experience two high tides and two low tides in a 24-hour DAY.

High tide at Bolinas Lagoon in California's Marin County in 1906. (U.S. Geological Survey)

Low tide at Bolinas Lagoon in California's Marin County in 1906. (U.S. Geological Survey)

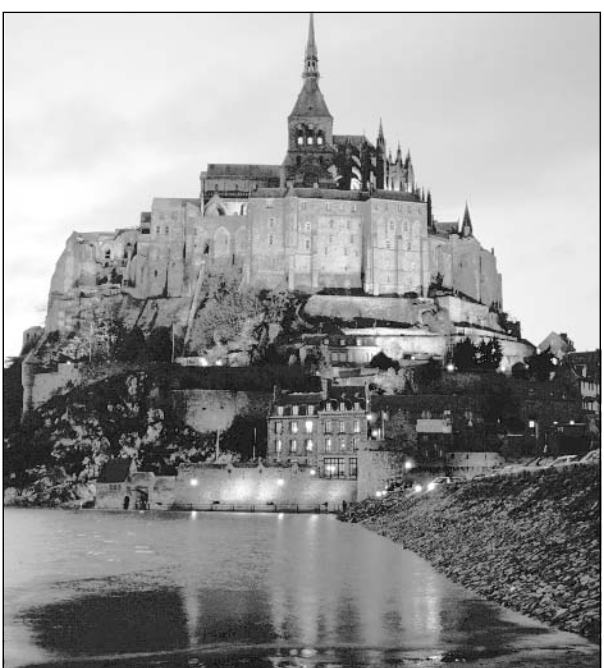
Till. Mass of unsorted and unstratified SEDIMENTS deposited by a GLACIER. Boulders and smaller rounded ROCKS are mixed with CLAY-sized materials.

Timberline. Another term for treeline, the BOUNDARY of tree growth on MOUNTAIN slopes. Above the timberline, TEMPERATURES are too cold for tree growth.

Time-space convergence. Concept explaining how TECHNOLOGY has enabled PLACES to seem closer, because the time to send a communication between two places, or the time to travel from one place to the other, has shortened. The history of transport is one of increased time-space convergence, as clipper ships, steam ships, trains, automobiles, and airplanes reduced the time of journeys. The radio, telegraph, telephone, and Internet allow for almost instantaneous communication, the ultimate in time-space convergence.

Time zones. The earth is divided into twenty-four standard time zones, each of which is fifteen DEGREES of LONGITUDE apart. The central MERIDIAN for the first time zone is the PRIME MERIDIAN, or zero degrees. Each central meridian is fifteen degrees apart, so all central meridians are a factor of five or ten degrees. Because political boundaries do not conform well to meridians in some PLACES, time zones do not follow meridians exactly, but are often adjusted to the political BOUNDARY.

Tombolo. Strip of SAND or other SEDIMENT that connects an ISLAND or



Mont-Saint-Michel, an ancient fortified island abbey, is connected to the mainland by a tombolo. (PhotoDisc)

SEA stack to the mainland. Mont-Saint-Michel is linked to the French mainland by a tombolo.

Topocide. Death of a PLACE, usually the result of INDUSTRIALIZATION, mining, or URBANIZATION.

Topographic map. MAP showing the detailed shape of the land using contours, which are imaginary lines drawn at equal ELEVATION above SEA LEVEL, with a regular contour interval. On an American topographic map, for example, contours might be shown for 20, 40, and 60 feet, and so on, above mean sea level. A standard set of symbols and colors is used in the production of topographic maps, so that a LEGEND is not necessary once a user becomes familiar with these maps. Topographic maps are used by hikers, campers, and engineers. The U.S. Geologic Survey produces topographic maps at SCALES of 1:24,000 and smaller scales.

Topography. Description of the natural LANDSCAPE, including LANDFORMS, RIVERS and other waters, and VEGETATION cover.

Topological space. Space defined in terms of the connectivity between LOCATIONS in that space. The nature and frequency of the connections are measured, while distance between locations is not considered an important factor. An example of topological space is a transport network diagram, such as a bus route or a MAP of an underground rail system. Networks are most concerned with flows, and therefore with connectivity.

Toponyms. PLACE names. Sometimes, names of features and SETTLEMENTS reveal a good deal about the history of a REGION. For example, the many names starting with "San" or "Santa" in the Southwest of the United States recall the fact that Spain once controlled that area. The scientific study of place names is toponymics.

Topophilia. Love of PLACE. Feelings or emotions that people associate with certain places. The home area or REGION hold a special place in the affections of many people and give them a sense of identity and belonging to a community.

Topsoil. In reclamation, all SOIL which will support plant growth, but normally the 8 to 12 inches (20-30 centimeters) of the organically rich top layer.

Tor. Rocky outcrop of blocks of ROCK, or corestones, exposed and rounded by WEATHERING. Tors frequently form in GRANITE, where three series of JOINTS often developed as the rock originally cooled when it was formed.

Tornado. Narrow vortex of rotating WINDS around a low-pressure center. Tornadoes are about 600 feet (200 meters) in diameter at ground level, and they travel across the land at speeds of up to 30 miles (50 km.) per hour. Within the tornado, windspeeds on average reach 270 miles (450 km.) per hour but can be even higher. Because of this, tornadoes are extremely destructive. Tornadoes can occur in many coun-

Narrow vortexes of wind rotating around low-pressure centers, tornadoes move across land surfaces at speeds of up to 30 miles (50 km.) per hour. (PhotoDisc)

tries, but the United States has the world's greatest frequency of tornadoes, especially in its Great Plains STATES.

Town. URBAN SETTLEMENT with a form of local self-government, such as a mayor. A town usually has more than twenty-five hundred residents and can be much larger. See also CITY.

Township and range. System of surveying and subdividing land quickly, introduced in the United States in 1785. Each township was a square with a side of six miles, or thirty-six square miles. Each square mile was then divided into four squares, each covering 160 acres. This was the smallest piece of land a farmer could buy. The legacy of this survey system is the checkerboard LANDSCAPE of the agricultural land of the Midwest.

Traction. Means by which a STREAM moves part of its load. Large PEBBLES, or even boulders, are dragged along, in contact with the bed of the stream. The process is traction; the material is the bedload.

Trade. Exchange of goods and services, with or without the use of currency. In modern economies, currency or money is the medium of trade. Trade opened the world to European influences, as mariners and explorers sought new sources of MINERALS and other trade goods. International trade is an important part of high-income economies and is regulated by agreements such as the General Agreement on Tariffs and Trade (GATT) and the World Trade Organization (WTO). Arguments for increased international trade include the creation of jobs in other countries that supply goods to wealthy markets, and the lower price of commodities in those countries. Arguments against international trade include the perpetuation of low-wage labor in poor countries and ENVIRONMENTAL DEGRADATION in some industries.

Trade winds. WINDS that converge toward the INTERTROPICAL CONVERGENCE ZONE. Trade winds move from the subtropical high-pressure zones of each HEMISPHERE toward the low-pressure BELT but are deflected by the CORIOLIS EFFECT and by friction, so that they produce the northeast trade winds in the NORTHERN HEMISPHERE and the southeast trade winds in the SOUTHERN HEMISPHERE. The name comes from the days when sail-powered ships carried goods between CONTINENTS. These warm and reliable winds were favored by sailors. Part of the circulation pattern known as Hadley cells.

Transculturation. Cultural mingling that occurs when two CULTURES are in close contact over a sustained period. The culture of modern Mexico, which combines Spanish and Amerindian cultures, is a good example of transculturation. Compare with ACCULTURATION.

Transferability. Economic term that describes the ability to move goods from one PLACE to another and to bear the costs incurred.

Transform faults. FAULTS that occur along DIVERGENT PLATE boundaries, or SEAFLOOR SPREADING zones. The faults run perpendicular to the spreading center, sometimes for hundreds of miles, some for more than five hundred miles. The motion along a transform fault is lateral or STRIKE-SLIP.

Transgression. Flooding of a large land area by the SEA, either by a regional downwarping of continental surface or by a global rise in SEA LEVEL.

Transhumance. Form of pastoral activity in which farmers take their grazing animals up to high ALPINE pastures during the spring, bringing them down to lower levels in the colder months. In cold CLIMATES, LIVESTOCK can even be kept indoors during the winter. Transhumance is practiced in the European Alps and in mountainous parts of Asia and Scandinavia.

Transit. Passage of a small object across the face of a larger object, such as a MOON passing across a PLANET.

Transpiration. Loss of moisture to the ATMOSPHERE through the leaves of plants. When considered together with EVAPORATION, the term EVAPOTRANSPIRATION is used.

Transportation. Movement of goods or people from one PLACE to another. In earlier times, and in some poor countries today, animals provide the means of transportation. Most countries now have mechanical transportation, such as trains, buses, automobiles, airplanes, and steamships. Improvements in transport and COMMUNICATIONS, especially in the nineteenth and twentieth centuries, led to what geographers call TIME-SPACE CONVERGENCE. Places were connected more quickly, easily, and cheaply, which contributed to globalization. Transportation based on the burning of FOSSIL FUELS is a major cause of GREENHOUSE GASES.

Transverse bar. Flat-topped body of SAND or gravel oriented transverse to the RIVER flow.

Transverse dunes. Asymmetrical SAND DUNES running at right angles to the prevailing WIND direction. They form where there is an abundant supply of sand and only moderate winds.

Transverse valley. River-cut VALLEY OR GORGE that runs perpendicular to the main STRIKE direction of a mountain CHAIN.

Transverse waves. See S WAVES.

Travertine. LIMESTONE formations such as STALACTITES and STALAGMITES that form in limestone CAVES and around calcareous SPRINGS. Also known as TUFA.

Travertine formation, the Liberty Cap, at Mammoth Hot Springs in Yellowstone National Park. (U.S. Geological Survey)

Treeline. See TIMBERLINE.

Trench. Long, deep shape in the OCEAN floor, close to a CONTINENT or an ISLAND ARC. Trenches are formed as part of SUBDUCTION, when OCEANIC CRUST is forced down beneath an adjacent TECTONIC PLATE. Adjacent to a trench is a zone of active VOLCANOES, formed by the heat, pressure, and melting of the descending material. The lowest PLACE on Earth is at the bottom of the Mariana Trench, more than 36,000 feet (11,000 meters) below MEAN SEA LEVEL.

Triassic. PERIOD of time about 225 to 195 million years ago at the beginning of the MESOZOIC ERA when dinosaurs lived.

Tributary. STREAM that joins its water with a larger stream. The smallest tributaries are tiny streams, numbered as first-order streams in a network (see STREAM ORDER). Some tributaries are themselves major RIVERS, such as the Missouri, a tributary of the Mississippi.

Trophic level. Different types of food relations that are found within an ECOSYSTEM. Organisms that derive food and ENERGY through PHOTOSYNTHESIS are called autotrophs (self-feeders) or producers. Organisms that rely on producers as their source of energy are called heterotrophs (feeders on others) or consumers. A third trophic level is represented by the organisms known as decomposers, which recycle organic waste.

Tropical cyclone. STORM that forms over tropical OCEANS and is characterized by extreme amounts of rain, a central area of calm AIR, and spinning WINDS that attain speeds of up to 180 miles (300 km.) per hour.

Tropical depression. STORM with WIND speeds up to 38 miles (64 km.) per hour.

Tropical rain forest. See RAIN FOREST, TROPICAL.

Tropical storm. STORM with WINDS of 38-70 miles (64-118 km.) per hour.

Tropics. The REGION of the earth lying between the tropic of CAPRICORN, 23.5 DEGREES south, and the tropic of CANCER, 23.5 degrees north. More than one-third of the earth's land lies in the Tropics, with CLIMATES ranging from the hot humid tropical RAIN FOREST to the hot arid tropical DESERT. TEMPERATURES in the Tropics are high all year, because the SUN is always nearly vertically overhead. The annual RANGE of temperature is 77-82 degrees Fahrenheit (25 to 28 degrees Celsius). SEASONS are not measured by temperature variation or by changes in length of DAY, but by the season of RAINFALL (except in the tropical rain forest, where it rains all year). The most spectacular climate change in the Tropics is the MONSOON; the dramatic onset of the Asian monsoon is both eagerly awaited and dreaded. The ancient Greeks believed that human life was not possible in the Tropics, because of the high temperatures, but today the tropical region of Southeast Asia contains about one-fifth of the world's POPULATION.

Tropopause. BOUNDARY layer between the TROPOSPHERE and the STRATOSPHERE.

Troposphere. Lowest and densest of Earth's atmospheric layers, marked by considerable TURBULENCE and a decrease in TEMPERATURE with increasing ALTITUDE.

Trough. Long, relatively gentle-sided depression or furrow, sometimes subdivided into many smaller troughs.

True horizon. See HORIZON, TRUE.

Tsunami. SEISMIC SEA WAVE caused by a disturbance of the OCEAN floor, usually an EARTHQUAKE, although undersea LANDSLIDES or volcanic ERUPTIONS can also trigger tsunami. A tsunami travels through the ocean at great speed; it has a small WAVE HEIGHT but long WAVE LENGTH. The Japanese word means "HARBOR wave," because when the tsunami reaches the COAST it grows tall and creates tremendous destruction. Tsunami have caused such destruction and loss of life that there is a warning system in place covering the Pacific Ocean, with stations in Alaska and Hawaii ready to transmit instant warning of impending tsunami. It is incorrect to use the term "tidal wave" for a tsunami, since TIDES have nothing to do with tsunami.

Tsunami warning. Second phase of a TSUNAMI alert; it is issued after the generation of a tsunami has been confirmed.

Tsunami watch. First phase of a TSUNAMI alert; it is issued after a large EARTHQUAKE has occurred at the seafloor.

Tufa. LIMESTONE or calcium carbonate deposit formed by PRECIPITATION from an alkaline LAKE. Mono Lake is famous for the dramatic tufa towers exposed by the lowering of the level of lake water. Also known as TRAVERTINE.

Tufa tower on California's Mono Lake. (Corbis)

Tuff. Compacted deposit that is 50 percent or more VOLCANIC ASH and DUST.

Tuff ring. Larger form of a MAAR.

Tumescence. Local swelling of the ground that commonly occurs when MAGMA rises toward the surface.

Tundra. The treeless far northern lands of Canada and Eurasia, covering about one-tenth of the earth's lands. There, the CLIMATE is so cold that only low plants can grow. The ground is snow-covered for eight or more months a year and PRECIPITATION is low. Plants of the tundra are adapted to a short growing season. The Inuit peoples of North America and the Saami of nothern Europe are native to the ARCTIC tundra. In high MOUNTAINS there is a second type of tundra, known as ALPINE tundra. TEMPERATURES there are too low for trees to grow, snow covers the ground for much of the year, and strong WINDS are frequent. Both types of tundra are fragile environments where development for mining, oil drilling, or even recreation threatens the ecosystems.

Tunnel vent. Central tube in a volcanic structure through which material from the earth's interior travels.

Turbulence. Rapid flow of water in rivers, in estuaries, and near ocean surfaces, and the movement of AIR in STORMS. High-speed WINDS and large-scale atmospheric phenomena usually create large differences in fluid velocity over relatively small distances. These highly sheared flows tend to be generically unstable when their otherwise smooth "laminar" motion is subjected to naturally occurring disturbances. The resulting oscillations in air or water velocity tend to grow rapidly in amplitude and can produce a chaotic, highly fluctuating state of fluid motion known as hydrodynamic turbulence. The turbulent motion of fluids is a universal phenomenon, occurring in a wide variety of environmental fluid flows, in the flow of air about aircraft and water about ship and submarine hulls, in the interior motions of stars, and in galactic jets and CLOUDS.

Typhoon. Name used for a HURRICANE or TROPICAL CYCLONE occurring in East Asia, in the East China Sea, and as far north as southern Japan.

U-shaped valley. Steep-sided VALLEY carved out by a GLACIER. Also called a glacial TROUGH.

U-shaped valley in England's Lake District. Erosion is particularly rapid at the heads of glaciers, which press rock fragments against the sides of the valleys they move through, widening and deepening the valleys by abrasion. (Ray Sumner)

Ubac slope. Shady side of a MOUNTAIN, where local or microclimatic conditions permit lower TIMBERLINES and lower SNOW LINES than occur on a sunny side.

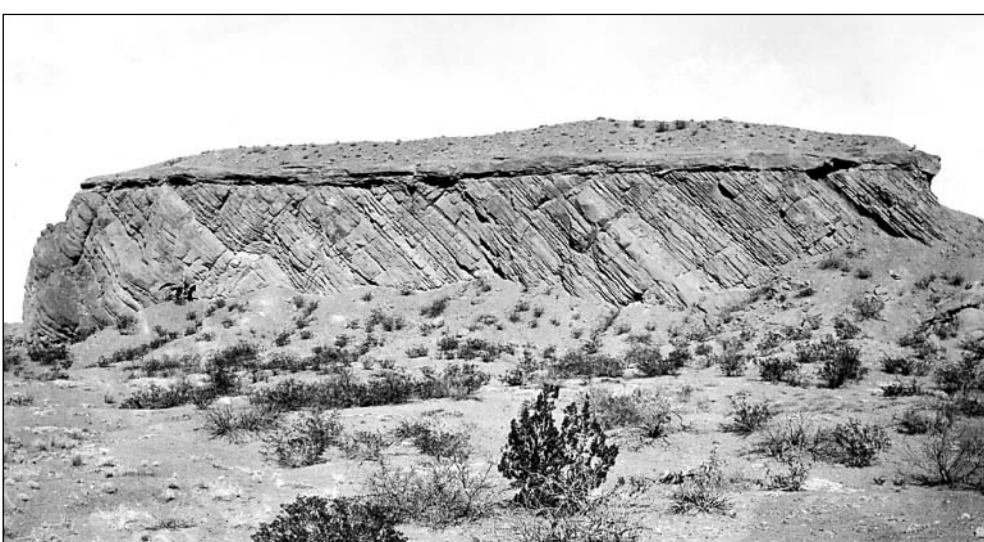
Ultimate base level. Level to which a STREAM can erode its bed. For most RIVERS, this is SEA LEVEL. For streams that flow into a LAKE, the ultimate base level is the level of the lakebed.

Ultramafic rocks. Dense, dark-colored, iron- and magnesium-rich silicate ROCKS composed primarily of the MINERALS olivine and pyroxene. They are the dominant rocks in the earth's MANTLE but also occur in some areas of the CRUST. Ultramafic rocks are important for what they contribute to the understanding of crust and mantle evolution. They also serve as an important source of economic commodities such as chromium, platinum, nickel, and diamonds, as well as talc and various decorative building stones.

Ultraviolet radiation. Electromagnetic radiation extending from just above the sensitivity of the human eye. Form of ENERGY that can cause chemical reactions; it has more energy than visible light and contributes to the breakdown of OZONE in Earth's ATMOSPHERE.

Unconfined aquifer. AQUIFER whose upper BOUNDARY is the WATER TABLE; it is also called a water table aquifer.

Unconformity. Interruption or break in the depositional sequence of SEDIMENTARY ROCKS, representing a long PERIOD of geologic time. This might result from a fall in SEA LEVEL or a tectonic event. Generally, an unconformity represents an erosional surface. Other SEDIMENTS later were deposited on top of this erosional surface. Near the bottom of the Grand Canyon walls lies the Great Unconformity.



This small mesa near San Lorenzo Arroyo in Arizona shows an unconformity overlying upthrust rock. (U.S. Geological Survey)

Underclass. Group of people who experience a form of poverty that keeps them isolated from the mainstream POPULATION and from the formal labor market. In the United States, persons with limited English-speaking skills, single parents, and the long-term unemployed are commonly members of the underclass. The underclass is also subject to increased levels of violence and higher-than-average levels of drug use, illness, and crime.

Underemployment. Phenomenon that occurs when people work less than they wish or less than full time. This is often a way to prevent some workers being fired or laid off.

Underfit stream. STREAM that appears to be too small to have eroded the VALLEY in which it flows. A RIVER flowing in a glaciated valley is a good example of underfit.

Uniformitarianism. Theory introduced in the early nineteenth century to explain geologic processes. It used to be believed that the earth was only a few thousand years old, so the creation of LANDFORMS would have been rapid, even catastrophic. This theory, called CATASTROPHISM, explained most landforms as the result of the Great Flood of the Bible, when Noah, his family, and animals survived the deluge. Uniformitarianism, in contrast, stated that the processes in operation today are slow, so the earth must be immensely older than a mere few thousand years.

Universal time (UT). See GREENWICH MEAN TIME.

Universal Transverse Mercator. Projection in which the earth is divided into sixty zones, each six DEGREES of LONGITUDE wide. In a traditional Mercator projection, the earth is seen as a sphere with a cylinder wrapped around the EQUATOR. UTM can be visualized as a series of six-degree side strips running transverse, or north-south.

Universalizing religion. Proselytic RELIGION; one that actively seeks to convert others to its belief system. Followers of a universalizing religion believe that their religion is appropriate for everyone. See also ETHNIC RELIGION.

Unstable air. Condition that occurs when the AIR above rising air is unusually cool so that the rising air is warmer and accelerates upward.

Upland. Land that is higher than nearby RIVER VALLEYS. A PLATEAU is one kind of upland.

Uplift. Rising of the earth's surface or the increase in distance between the earth's surface and its center.

Upper mantle. Comparatively rigid part of the earth's interior below the CRUST of the earth down to about 700 kilometers, composed of magnesium and iron-rich ROCK.

Upthrown block. When EARTHQUAKE motion produces a FAULT, the block of land on one side is displaced vertically relative to the other. The higher is the upthrown block; the lower is the downthrown block.

Upwelling. OCEAN phenomenon in which warm SURFACE WATERS are pushed away from the COAST and are replaced by cold waters that carry more nutrients up from depth.

Urban area. In many PLACES, a SETTLEMENT with two thousand or more residents is considered urban; smaller settlements are RURAL. Generally the POPULATION of an urban area is engaged in secondary or TERTIARY economic activity. A large urban settlement is a CITY or MEGALOPOLIS.

Urban heat island. Cities experience a different MICROCLIMATE from surrounding REGIONS. The CITY TEMPERATURE is typically higher by a few DEGREES, both DAY and night, because of factors such as surfaces with higher heat absorption, decreased WIND strength, human heat-producing activities such as power generation, and the layer of AIR POLLUTION (DUST DOME).

Urbanization. Increase in the proportion of a POPULATION living in URBAN AREAS.

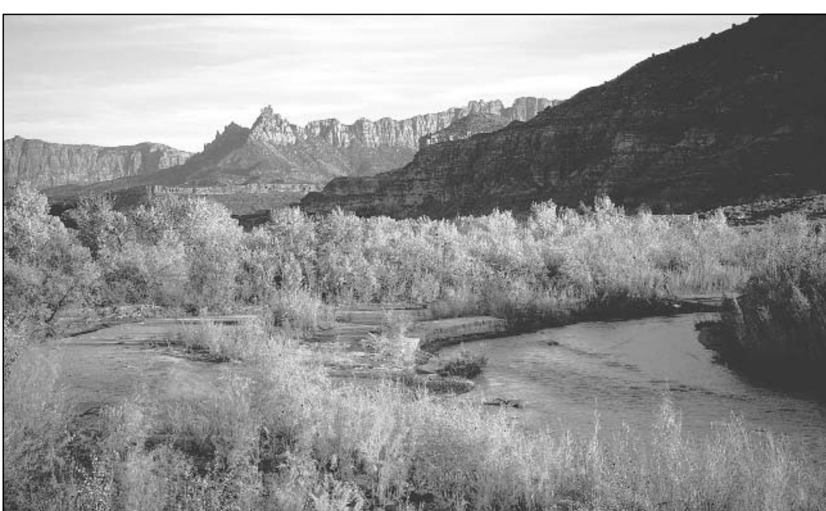
UTC. See COORDINATED UNIVERSAL TIME.

UTM. See UNIVERSAL TRANSVERSE MERCATOR.

Uvala. Slavic term for an enlarged SINKHOLE in LIMESTONE, or a KARST VALLEY.

Vadose zone. The part of the SOIL also known as the zone of AERATION, located above the WATER TABLE, where space between particles contains AIR.

Valley. Natural LANDFORM in which a long low shape is surrounded by higher valley sides reaching up to a valley crest. Valleys are eroded over



Valleys are natural landforms in which long, low shapes are surrounded by higher valley sides reaching up to crests. Valleys are eroded over time by streams, or sometimes by glaciers. (PhotoDisc) time by STREAMS, or sometimes by GLACIERS. RIFT VALLEYS are created by tectonic movement. RIVER VALLEYS have been the hearths of many great CULTURES of the past, such as the Egyptians on the Nile River.

Valley glacier. See ALPINE GLACIER.

Valley train. Fan-shaped deposit of glacial MORAINE that has been moved down-valley and redeposited by MELTWATER from the GLACIER.

Van Allen radiation belts. Bands of highly energetic, charged particles trapped in Earth's MAGNETIC FIELD. The particles that make up the inner BELT are energetic protons, while the outer belt consists mainly of electrons and is subject to DAY-night variations.

Varnish, desert. Shiny black coating often found over the surface of ROCKS in arid REGIONS. This is a form of OXIDATION or CHEMICAL WEATHERING, in which a coating of manganese oxides has formed over the exposed surface of the rock.

Varve. Pair of contrasting layers of SEDIMENT deposited over one year's time; the summer layer is light, and the winter layer is dark.

Vegetation. The plant life of an area. The four broad types are FOREST, GRASSLANDS, TUNDRA, and DESERT (or XEROPHYTIC). Forests are found in the TROPICS and the midlatitudes, wherever there is sufficient RAINFALL. Grassland dominates in REGIONS of lower rainfall. Tundra vegetation is small in size because of high TEMPERATURES and a permanently frozen ground surface known as PERMAFROST. Desert vegetation is adapted to low PRECIPITATION, less than one foot (30 centimeters) per year. Deserts are found in the Tropics and in midlatitudes.

Vein. MINERAL deposit that fills a crack; veins form by PRECIPITATION of minerals from fluids.

Veld. South African term for GRASSLANDS found when the early Dutch settlers, or Boers, trekked inland onto the PLATEAU. Afrikaans word for "field." Southern Africa's plateau REGION is known as the high veld.

Ventifacts. PEBBLES on which one or more sides have been smoothed and faceted by ABRASION as the WIND has blown SAND particles.

Vernacular region. CULTURE REGION that is identified by both the majority of people living within the region and by people living outside the region. People living in a vernacular region have a sense of regional identity. The vernacular region usually has a name that is widely understood by large numbers of people. Vernacular regions have a regional identity associated with the name. An example of a vernacular region in the United States is Appalachia.

Vernal equinox. See EQUINOX.

Village. Small SETTLEMENT, usually in a RURAL area. URBAN geographers regard a village as being larger than a HAMLET but smaller than a TOWN. Generally, this means that a village has fewer than twenty-five hundred residents, most of whom are engaged in agricultural activity.

Volcanic ash. Also known as volcanic DUST, the fine pyroclastic material thrown into the AIR in explosive volcanic ERUPTIONS. These particles are small enough to be held in SUSPENSION in the ATMOSPHERE, and can be spread around the whole earth by upper-level WINDS. The eruption of the Philippines' Mount Pinatubo in June, 1991, sent about twenty million tons of volcanic ash, dust, and gases into the atmosphere. The resulting cloud was spread by global winds, producing a band around the entire earth, extending from twenty DEGREES north LATITUDE to thirty degrees north latitude. Because of the increased reflection of SOLAR RADIATION, TEMPERATURES were slightly lower than usual for two years following the eruption.

Volcanic earthquakes. Small-magnitude EARTHQUAKES that occur at relatively shallow depths beneath active or potentially active VOLCANOES.

Volcanic island arc. Curving or linear group of volcanic ISLANDS associated with a SUBDUCTION ZONE. See also OCEANIC ISLANDS.

Volcanic neck. The throat of a VOLCANO, or the pipelike opening in which the LAVA rises up before an explosion. Sometimes the lava solidifies inside the opening, then the surrounding cone is eroded away, leaving the neck exposed as a tall, steep-sided LANDFORM. Ship Rock, New Mexico, and Devil's Tower, Wyoming, are well-known volcanic necks.

Volcanic plumes. Material thrown up from the surface by ERUPTIONS; they indicate high volcanic activity.

Volcanic rock. Type of IGNEOUS ROCK that is erupted at the surface of the earth; volcanic rocks are usually composed of larger crystals inside a fine-grained matrix of very small crystals and glass.

Volcanic tremor. Continuous vibration of long duration, detected only at active VOLCANOES.

Volcano. Geologic phenomenon produced by the ERUPTION of MAGMA from beneath a PLANET's surface; it creates MOUNTAINS that often display a cone shape. Volcanic activity usually occurs in SUBDUCTION ZONES, in SEAFLOOR SPREADING zones, and at HOT SPOTS. When one TECTONIC PLATE is pushed or dragged beneath another plate, the pro-

Oregon's Mount Hood, part of the Pacific Coast's Cascade Range, is a beautiful example of a cone-shaped volcano. As is the case with Japan's Mount Fuji, Mount Hood's appearance is enhanced by the absence other nearby mountains. (PhotoDisc) cess is called SUBDUCTION. Friction melts the descending ROCK, which is also full of steam, and the hot magma rises until it bursts through the overlying plate in a volcano. When plates diverge at a seafloor spreading zone, magma spreads out from the RIFT, forming long MID-OCEAN RIDGES of volcanoes. Hot spots, or MANTLE PLUMES, are small REGIONS of the earth's CRUST where magma rises in a thin stream to the surface, as in Hawaii, or close to the surface, as in Yellowstone National Park. Volcanic cones are classified by their composition into CINDER CONES, SHIELD VOLCANOES, and COMPOSITE CONES or STRATOVOLCANOES.

Volcanology. Scientific study of VOLCANOES.

Voluntary migration. Movement of people who decide freely to move their place of permanent residence. It results from PULL FACTORS at the chosen destination, together with PUSH FACTORS in the home situation.

Wadi. Arabic word for a WASH, or dry STREAMBED.

Warm cloud. Visible SUSPENSION of tiny water droplets at TEMPERATURES above freezing.

Warm front. See FRONT.

Warm temperate glacier. GLACIER that is at the melting TEMPERATURE throughout.

Wash. Dry STREAMBED, filled with ALLUVIUM, in an arid area. ARROYO is the Spanish word for this feature.

Water cycle. Continuous movement of the water of the earth's HYDROSPHERE. EVAPORATION from the OCEAN is followed by CONDENSATION into CLOUDS, then PRECIPITATION. RUNOFF returns water to the ocean, where it is again evaporated. Also called the HYDROLOGIC CYCLE.

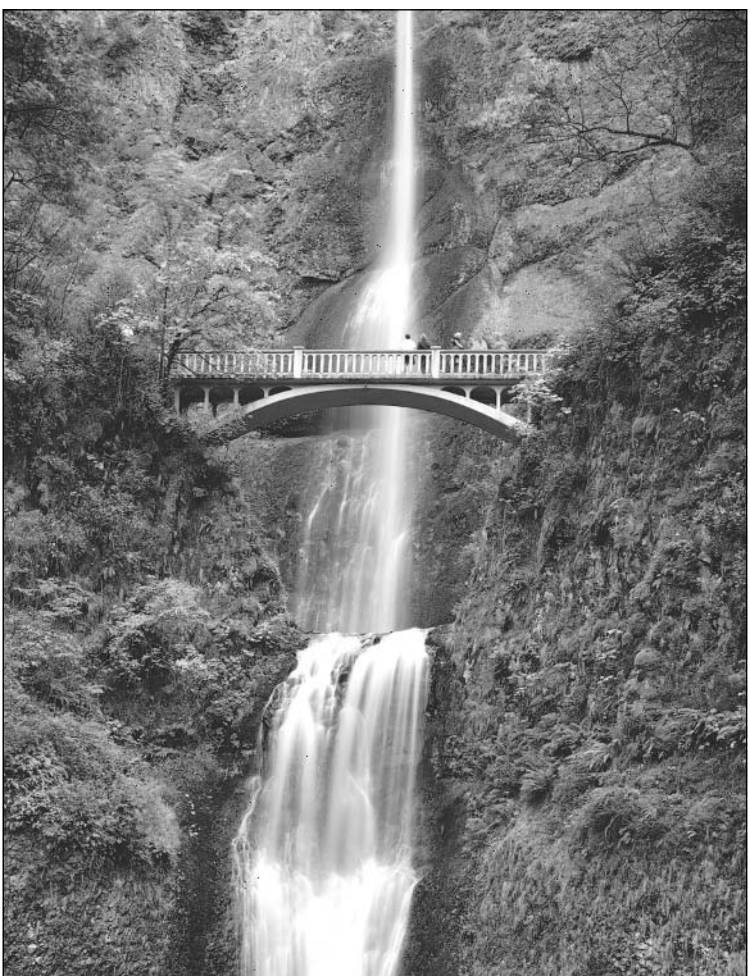
Water gap. Low point in a RIDGE through which a STREAM flows. Generally, a water gap indicates UPLIFT of the REGION while the stream has continued to erode its bed.

Water power. Generally means the generation of electricity using the ENERGY of falling water. Usually a DAM is constructed on a RIVER to provide the necessary height difference. The potential energy of the falling water is converted by a water turbine into mechanical energy. This is used to power a generator, which produces electricity. Also called HYDROELECTRIC POWER. Another form of water power is tidal power, which uses the force of the incoming and outgoing TIDE as its source of energy.

Water resources. All the SURFACE WATER and GROUNDWATER that can be effectively harvested by humans for domestic, industrial, or agricultural uses.

Water table. The depth below the surface where the zone of AERATION meets the zone of SATURATION. Above the water table, there may be some SOIL MOISTURE, but most of the pore space is filled with air. Below the water table, pore space of the ROCKS is occupied by water that has percolated down through the overlying earth material. This water is called GROUNDWATER. In practice, the water table is rarely as flat as a table, but curved, being far below the surface in some PLACES and even intersecting the surface in others. When GROUNDWATER emerges at the surface, because it intersects the water table, this is called a SPRING. The depth of the water table varies from SEASON to season, and with pumping of water from an AQUIFER.

Waterfall. Part of a STREAM where there is a steep, nearly perpendicular, fall in the STREAMBED. Waterfalls often form where there is resistant ROCK in one part of the streambed and softer rock in the next section. The softer rock is eroded more rapidly, leaving a rock ledge over which the water then falls. Other waterfalls are caused by EARTHQUAKE faulting or by stream REJUVENATION due to UPLIFT. Over time, the edge of the waterfall recedes because of EROSION of the lip. Another term for a waterfall is a KNICKPOINT.



Oregon's Multnomah Falls. (PhotoDisc)

Watershed. The whole surface area of land from which RAINFALL flows downslope into a STREAM. The watershed comprises the STREAMBED or CHANNEL, together with the VALLEY sides, extending up to the crest or INTERFLUVE, which separates that watershed from its neighbor. Each watershed is separated from the next by the drainage DIVIDE. Also called a DRAINAGE BASIN.

Waterspout. TORNADO that forms over water, or a tornado formed over land which then moves over water. The typical FUNNEL CLOUD, which reaches down from a CUMULONIMBUS CLOUD, is a narrow rotating STORM, with WIND speeds reaching hundreds of miles per hour.

Wave. Moving SWELL on the surface of a body of water. In the deep OCEAN are waves of oscillation (waves of transition), where the wave ENERGY, but not the water, is moving forward. The friction of WINDS blowing over the surface of the ocean creates waves. As ocean waves approach the SHORE and water becomes shallower, they change to waves of translation, in which the water and the energy both move toward the shore. See also BREAKER.

Wave crest. Top of a WAVE.

Wave-cut platform. As SEA CLIFFS are eroded and worn back by WAVE attack, a wave-cut platform is created at the base of the cliffs. ABRASION by ROCK debris from the cliffs scours the platform further, as waves wash to and fro and TIDES ebb and flow. The upper part of the wave-cut platform is exposed at high tide. These areas contain rockpools, which are rich in interesting MARINE life-forms. Offshore beyond the platform, a wave-built TERRACE is formed by DEPOSITION.

Wave height. Vertical distance between one WAVE CREST and the adjacent WAVE TROUGH.

Wave length. Distance between two successive WAVE CRESTS or two successive WAVE TROUGHS.

Wave trough. The low part of a WAVE, between two WAVE CRESTS.

Weather. DAY-to-day variations in atmospheric conditions, including TEMPERATURE, precipitation, humidity, cloud cover, winds or STORMS, and ATMOSPHERIC PRESSURE conditions. Weather is constantly changing, and scientists study it so as to make predictions or forecasts. CLIMATE is the long-term average of recorded weather data.

Weather analogue. Approach to WEATHER FORECASTING that uses the WEATHER behavior of the past to predict what a current weather pattern will do in the future.

Weather forecasting. Attempt to predict WEATHER patterns by analysis of current and past data.

Weathering. The change or breaking down of ROCK when it is exposed at the earth's surface. PHYSICAL WEATHERING is the breaking down into smaller pieces, or disintegration; CHEMICAL WEATHERING is the process of decomposition through chemical change. Weathering is a prelude to EROSION.

Well. Artificial entry into the WATER TABLE. Both farmers and cities sink wells to tap GROUNDWATER.

Western Hemisphere. The half of the earth containing North and South America; generally understood to fall between LONGITUDES 160 DEGREES east and 20 degrees west.

Wetlands. PLACES where the ground is saturated with water, Specialized VEGETATION, called hygrophytic plants, grows there. Wetlands are a transition between aquatic ECOSYSTEMS and terrestrial ecosystems. COASTLINES where DEPOSITION is occurring commonly have wetlands in estuaries and infilled LAGOONS. These wetlands are classed as SALT MARSH. Tropical COASTAL WETLANDS have MANGROVE SWAMPS. There can be wetlands with FRESH WATER, as in PEAT BOGS in northern LATITUDES or backswamps on FLOODPLAINS. Wetlands are rich biological reservoirs but are greatly endangered by DEVELOPMENT.

Wetlands are places in which the ground is permanently saturated with water. Wetlands form transitions between aquatic and terrestrial ecosystems. (PhotoDisc)

White water. Turbulent and frothy portions of RAPIDS; so called because of the tendency of the water to form white foam.

Wilderness. Originally, a PLACE where no humans lived, generally because of harsh conditions. In the second half of the twentieth century, as roads were constructed into MOUNTAINS and FORESTS and off-road vehicles became widely used for recreation, people came to see a need for preservation of parts of the COUNTRY that would only be accessible on foot—wilderness areas. The Wilderness Act of 1964 defined "wilderness" as "a place that is not controlled by humans, where natural ecological processes operate freely and where its primeval character and influences are retained; a place that is not occupied or modified by mankind, where humans are visitors, and the imprint of their activity is largely unnoticeable; a place with outstanding opportunities for the solitude necessary for a primitive and unconfined recreation experience." Numerous areas have been set aside as wilderness areas in NATIONAL PARKS, in national forests, and on land controlled by the Bureau of Land Management. In the year 2000, there were forty-nine national park wilderness areas in the United States.

Willy willy. Australian term for a DUST DEVIL. (Americans sometimes mistakenly believe it is an Australian term for HURRICANE.)

Wilson cycle. Creation and destruction of an OCEAN BASIN through the process of SEAFLOOR SPREADING and SUBDUCTION of existing ocean basins.

Wind. Horizontal movement of AIR relative to the earth's surface, caused by differences in ATMOSPHERIC PRESSURE. These pressure differences arise largely because of unequal heating of the earth's surface by the SUN's rays. Winds play an important role in WEATHER and CLIMATE. Winds that blow predominantly from one direction are called prevailing winds. Before the invention of steamships, sailing ships relied on prevailing winds to cross OCEANS.

Wind energy. Power generated using the force of the WIND. Windmills have provided wind energy for centuries, generally to pump water or grind grains. In the late twentieth century, concern about the use of FOSSIL FUELS led to research into generating power through wind energy, which is a RENEWABLE and nonpolluting source of energy. California has been a world leader in modern wind-generation TECHNOL-

This array of wind turbines at Altamont in Northern California is part of one of the largest arrays of wind turbines in the United States. (PhotoDisc) ogy, with major wind farms located near Palm Springs. Although this is a sustainable energy form, some people are opposed to the appearance of fields of wind generators.

Wind gap. Abandoned WATER GAP. The Appalachian Mountains contain both wind gaps and water gaps.

Windbreak. Barrier constructed at right angles to the prevailing WIND direction to prevent damage to crops or to shelter buildings. Generally, a row of trees or shrubs is planted to form a windbreak. The feature is also called a shelter belt.

Windchill. MEASUREMENT of apparent TEMPERATURE that quantifies the effects of ambient WIND and temperature on the rate of cooling of the human body.

Windward. Front or exposed side of a MOUNTAIN or RANGE is the windward side. A RAIN SHADOW is usually located on the windward side of a mountain range. Compare to LEEWARD.

Winter solstice. DAY on which winter begins; in the NORTHERN HEMISPHERE, about December 21, and in the SOUTHERN HEMISPHERE, about June 21.

Woodlands. VEGETATION communities in which the upper canopy is not completely closed because the trees are more widely spaced than in a FOREST. In the intervening spaces, shrubs and other groundcover grow. Woodland is a response to drier conditions, where RAINFALL is not sufficient for true forest to grow. SAVANNA woodland grades into savanna GRASSLAND with increasing ARIDITY.

Woodlands differ from forests in having upper canopies that are not completely closed to sunlight because their trees are more widely spaced than those in forests. (PhotoDisc)

World Aeronautical Chart. International project undertaken to map the entire world, begun during World War II.
World Bank. Bank providing developmental assistance in the form of financial loans to client countries. The World Bank and the International Monetary Fund (IMF) were created after World War II, following the Bretton Woods Conference of 1944. There were 160 members of the World Bank in 2000.
World city. CITY in which an extremely large part of the world's economic, political, and cultural activity occurs. In the year 2000, the three world cities were London, New York, and Tokyo.

Xenolith. Smaller piece of ROCK that has become embedded in an IGNEOUS ROCK during its formation. It is a piece of older rock that was incorporated into the fluid MAGMA.
Xeric. Description of SOILS in REGIONS with a MEDITERRANEAN CLIMATE, with moist cool winters and long, warm, dry summers. Since summer is the time when most plants grow, the lack of SOIL MOISTURE is a limiting factor on plant growth in a xeric ENVIRONMENT.
Xerophytic plants. Plants adapted to arid conditions with low PRECIPITATION. Adaptations include storage of moisture in tissue, as with cactus plants; long taproots reaching down to the WATER TABLE, as with DESERT shrubs; or tiny leaves that restrict TRANSPIRATION.

Yardangs. Small LANDFORMS produced by WIND EROSION. They are a series of sharp RIDGES, aligned in the direction of the wind.
Yazoo stream. TRIBUTARY that flows parallel to the main STREAM across the FLOODPLAIN for a considerable distance before joining that stream. This occurs because the main stream has built up NATURAL LEVEES through flooding, and because RELIEF is low on the floodplain. The yazoo stream flows in a low-lying wet area called backswamps. Named after the Yazoo River, a tributary of the Mississippi.

Zero population growth. Phenomenon that occurs when the number of deaths plus EMIGRATION is matched by the number of births plus IMMIGRATION. Some European countries have reached zero population growth.
Zone of ablation. See ABLATION, ZONE OF.
Zone of accumulation. See ACCUMULATION, ZONE OF.
Zone of aeration. See AERATION, ZONE OF.
Zone of saturation. See SATURATION, ZONE OF.
Zoning. Land-management tool used to limit uses and define conditions and extent of use.

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Regional Geography

Zich, Arthur. "Modern Botswana, The Adopted Land." *National Geographic* 178, no. 6 (December, 1990): 70-97. An account of conditions in Botswana, including its democracy, current economy, its trade in diamonds and beef, and the Okavango Delta and its wildlife.

Zwingle, Erla. "Morocco." *National Geographic* 190, no. 4 (October, 1996): 98-125. Overview of modern Morocco, its history, its current economic conditions, and, in particular, its Berber people and their culture.

Europe

Physical Geography

Blake, S. F., and Alice C. Atwood. *Geographical Guide to Floras of the World: Western Europe.* Port Jervis, N.Y.: Lubrecht and Cramer, 1974. Extensive guide to the floras of areas such as Scandinavia, the Low Countries, the British Isles, Iberia, France, Italy, and the Netherlands.

Kuusia, K. *Forest Resources in Europe.* New York: Cambridge University Press, 1995. Provides a detailed country-by-country account of the increase in forest resources in Europe over the past forty years and what needs to be done to preserve the sustainability and biodiversity of Europe's forest ecosystems.

Human Geography

Germek, Bronislaw. *The Common Roots of Europe.* Translated by S. Mitchell and R. Hunt. Oxford, England: Polity Press, 1997. Discusses unity, variety, and collective identity in medieval Europe, social and economic structures in East and West, and the continuity and change in European identity in the intervening centuries.

Haudry, Jean. *The Indo-Europeans.* Washington, D.C.: Scott-Townsend, 1998. Study of the roots of the Indo-European peoples emphasizing Europe, their migrations, and evolution into the present day.

Kiernan, Victor. *Lords of Human Kind: European Attitudes to Other Cultures in the Imperial Age.* London: Serif and Pixel Press, 1996. Using a great array of sources—missionaries' memoirs, the letters of diplomats' wives, explorers' diaries, and the work of writers as diverse as Voltaire, William

Makepeace Thackeray, Oliver Goldsmith and Rudyard Kipling—the author searches the full range of European attitudes to other peoples.

Unwin, Tim. *A European Geography.* Reading, Mass.: Addison-Wesley, 1998. Chapters in this volume cover a wide swath of Europe such as the peopling of Europe, the Celts, the peopling of Finland, European languages, religious dimensions of Europeans, and cultural landscapes.

Economic Geography

Grant, Wyn. *The Common Agricultural Policy.* New York: St. Martin's Press, 1997. Examines the European Common Agricultural Policy and its impact on trade between the United States and Europe. This study argues for a new set of objectives designed to deliver effective agricultural production at an acceptable cost and attuned to the growing concerns of citizens about food quality.

Holden, Mike J., and David Garrod. *The Common Fisheries Policy.* Williston, Vt.: Blackwell, 1996. Focuses on the conservation policy because it generated the most controversy, which continues to intensify even as fish stocks deteriorate. For many the conservation policy is the Common Fisheries Policy, apparently a disastrous failure.

Laux, James Michael. *The European Automobile Industry.* Indianapolis, Ind.: Macmillan, 1992. Looks at motor vehicle manufacturing on the Continent from 1890 to the present, paying particular attention to the postwar spurt of growth that established which of Europe's various automakers would prevail. He examines how European factory owners emulated American success in production and sales between the wars, how the postwar market boom chipped away at American dominance of the industry, and how Japanese models in turn began to cut into the world market in the 1980's.

Regional geography

Belt, Don. "Sweden." *National Geographic* 184, no. 2 (August, 1993): 2-35. Overview of modern Sweden, its culture and how it relates to the world, especially its closest neighbors, Denmark, Finland, and Norway.

Coniff, Richard. "Ireland." *National Geographic* 186, no. 3 (September, 1994): 2-36. An overview of present-day Ireland. Economic conditions have improved since manufacturing surpassed farming in the island nation.

Keillor, Garrison. "Civilized Denmark." *National Geographic* 194, no. 1 (July, 1998): 50-73. An overview of present-day Denmark and its society.

Vulliamy, Ed. "Romania's New Day." *National Geographic* 194, no. 3 (September, 1998): 35-59. An overview of Romania and its postcommunist society and the changes that are occurring.

Ward, Andrew. "Scotland." *National Geographic* 190, no. 3 (September, 1996): 2-27. Overview of modern Scotland, its history, and its current yearning for independence from England and the United Kingdom.

Asia

Physical Geography

Hornocker, Maurice. "Siberian Tigers." *National Geographic* 191, no. 2 (February, 1997): 100-109. Only a few hundred survive in the wild. While zoos work to maintain the animal's genetic diversity, Russian and American scientists are pooling their efforts in the fight to save this magnificent creature from extinction. This article outlines the struggle, which includes the effects of poaching and habitat destruction.

Hutchison, Charles S. *Southeast Asian Oil, Gas, Coal and Mineral Deposits.* New York: Oxford University Press, 1996. Includes chapters on topics such as the oil and gas basins of Malaysia, Indonesia, and the Philippines, and coal, iron ore, tungsten, and tin deposits.

Knott, Cheryl. "Orangutans." *National Geographic* 194, no. 2 (August, 1998): 30-57. A study of a family of orangutans in Gunung Palung National Park near the west coast of Borneo.

Laidler, Liz, and Keith Laidler. *China's Threatened Wildlife.* Poole, Dorset, England: Blandford Press, 1999. This profiles twenty of China's more attention-getting endangered species: sixteen mammals, two birds, the giant salamander, and the Chinese alligator. It opens with a chapter describing China's eight distinct vegetation zones, ranging from tropical rainforest to alpine.

Moullade, Michel, and A. E. M. Naim. *Phanerozoic Geology of the World.* New York: Elsevier Science, 1991. Has chapters with titles such as "Southern Africa," "India," "Pakistan," "Late Precambrian and Paleozoic Rocks of Iran and Afghanistan," and "China."

Pant, Govind B., and Rupa K. Kumar. *Climates of South Asia.* New York: John Wiley and Sons, 1997. Explores the climates of countries in Southern Asia—India, Pakistan, Sri Lanka, Bangladesh, Nepal, Bhutan, and a few island countries of the Indian Ocean—using charts, diagrams, and data.

Schaller, George B. *Wildlife of the Tibetan Steppe.* Chicago: University of Chicago Press, 1998. Provides a detailed look at the flora and fauna of the Chang Tang, a remote Tibetan steppe. The plains ungulates are the main focus, especially the Tibetan antelope.

Verma, R. K. *Geodynamics of the Indian Peninsula and the Indian Margin.* Rotterdam, Netherlands: A. A. Balkema, 1991. On the geological history and evolution of the Indian Continental Shelf. Gravity fields, geology, and tectonics, radioactivity and heat sources, seismicity, and geodynamics of the Himalayas.

Ward, Geoffrey C. "Making Room for Wild Tigers." *National Geographic* 192, no. 6 (December, 1997): 2-35. An analysis of the work being done to accommodate all five subspecies of tigers in the increasingly densely populated areas of Asia where the animal is found.

_______. "India's Wildlife Dilemma." *National Geographic* 181, no. 5 (May, 1992): 2-29. The key problem is that growing numbers of poverty-stricken farmers compete for land with diverse wildlife species. This is threatening the future of India's unique natural heritage.

Wenshi, Pan. "New Hope for China's Giant Pandas." *National Geographic* 187, no. 2 (February, 1995): 100-115. Out of perhaps 1,200 pandas that remain in China, about 230 live in the Qin Ling area in Shaanxi Province in central China at elevations between 4,000 feet (1,200 meters) and 10,000 feet (3,000 meters). This is a look at a small family of pandas in that area.

HUMAN GEOGRAPHY

Kublin, Michael, and Hyman Kublin. *India.* Boston: Houghton Mifflin, 1991. Introduces the history and civilization of India. It includes a discussion of the problems facing Pakistan and Bangladesh.

Lardy, Nicholas R. *Agriculture in China's Modern Economic Development.* New York: Cambridge University Press, 1984. Explores the relationship between the Chinese peasantry, who are the fundamental base of support for the revolutionary Chinese Communist Party, and the state-led economic system established by the Party after 1949.

Schirokauer, Conrad. *A Brief History of Chinese Civilization.* Orlando, Fla.: HBJ College & School Division, 1991. Includes considerable material on the classical civilization of China, including Confucius, the Buddhist period, and the peoples.

_______. *A Brief History of Japanese Civilization.* Orlando, Fla.: HBJ College & School Division, 1993. Includes discussion of Shinto, samurai, the aristocracy, and even the Mongol invasion.

Songoiao, Zhao. *Geography of China: Environment, Resources, Population, and Development.* New York: John Wiley and Sons, 1994. Using a systematic and regional approach, this volume offers a comprehensive depiction of official population numbers, land and resource usage in the face of sobering population increase, population problems including ethnic structure and family planning, and a pattern of historical and economic development over China's long and interesting history.

ECONOMIC GEOGRAPHY

Gamaut, Rose Gregory, Guo Shutian, and Ma Guonon, eds. *The Third Revolution in the Chinese Countryside.* New York: Cambridge University Press, 1995. First section covers the issues of poverty in China and feeding the population. The second section describes the agricultural markets in China and the price reform of agricultural products. The next two parts discuss international and regional issues of China's agricultural economy.

Kalirajan, Kail P., ed. *Productivity and Growth in Chinese Agriculture.* New York: St. Martin's Press, 1999. Gauges the impact of economic and institutional reforms on agricultural productivity in China using the most recent farm household survey data. Results demonstrate the dynamic nature of Chinese farm households, particularly in relation to the changing demands placed on agriculture, especially the grain sector.

Pecht, Michael G., Wang Yong Wen, and Jiang Jun Lu. *The Electronics Industry in China.* Boca Raton, Fla.: CRC Press, 1999. Documents the technologies, capabilities, and infrastructure that has made China a major player in the Asian electronics industry.

Van Der Eng, Pierre. *Agricultural Growth in Indonesia Since 1880: Productivity Change and Policy Impact Since 1880.* New York: St. Martin's Press, 1996. Assesses long-term trends in agricultural production and productivity in Indonesia since 1880, providing an inventory of agricultural policies. It evaluates the impact of these policies on agricultural production, especially production of the country's main food and export crops. Appendices with statistics on prices, employment, livestock, and arable land.

Regional Geography

Allen, Thomas B. "Turkey." *National Geographic* 185, no. 5 (May, 1994): 2-35. Overview of modern Turkey including discussion of its history, roots of the modern-day state, the legacy of Kemal Ataturk, and the tension between Islamic Turkey, which exists in the countryside, and secular, urban Turkey. There is some discussion of the Kurdish minority.

Cockburn, Andrew. "Yemen." *National Geographic* 197, no. 4 (April, 2000): 30-53. An overview of modern Yemen, the land of the Queen of Sheba. It shows that Yemen is a land where a very traditional Arab culture is still dominant.

McCarry, John. "The Promise of Pakistan." *National Geographic* 192, no. 4 (October, 1997): 49-73. An overview of modern Pakistan, its roots, cultures, peoples, geography, agriculture, and its problems.

Reid, T. R. "Malaysia." *National Geographic* 192, no. 2 (August, 1997): 100-121. Overview of Malaysia, a mix of Muslim Malays, Buddhist Chinese, and Hindus, and its more recent development.

Theroux, Peter. "Syria, Behind the Mask." *National Geographic* 190, no. 1 (July, 1996): 106-131. An overview of modern Syria. It tends to focus on the mellowing of the current regime and its reaching out to the West.

Vesilind, Prit J. "Sri Lanka." *National Geographic* 191, no. 1 (January, 1997): 111-133. Overview of modern Sri Lanka including the strife which exists between Hindu Tamils and the Buddhist Sinhalese.

Ward, Geoffrey C. "India." *National Geographic* 191, no. 5 (May, 1997): 2-57. Overview of modern India, its complexity, diverse peoples, large population, its great poverty, and its many accomplishments.

Waterlow, Julia. *China.* New York: Bookwright Press, 1990. Introduction to the geography, climate, schools, sports, food, recreation, and culture of China.

Australia, Pacific, and Antarctica

Physical Geography

Blainey, Geoffrey. *Rush That Never Ended: A History of Australian Mining.* 4th ed. Melbourne, Australia: Melbourne University Press, 1993. Australia is one of the world's great sources of mineral treasure. The finding and development of minerals, oil, and natural gas have influenced Australian racial attitudes, unionism, religious life, law, and politics.

Conacher, Jeannette, and Arthur Conacher, eds. *Rural Land Degradation in Australia.* New York: Oxford University Press, 1995. Examines the degradation of Australia's ecosystems, the problems associated with the increasing use of synthetic chemicals, and the direct and underlying causes of land degradation. It also looks at broader social and economic implications, and places the nature of the overall problem in its global context.

Darcavel, John. *Fashioning Australia's Forests.* New York: Oxford University Press, 1996. Weaves together the story of industrial development and forest use with the slow acceptance of the case for forest conservancy.

Flannery, Tim F. *Mammals of the Southwest Pacific and Moluccan Islands.* Ithaca, N.Y.: Cornell University Press, 1995. Draws together the results of his five-year field survey and literature review on the mammals of an area extending from the islands just east of Sulawesi (Celebes, Indonesia) in the Moluccas, to the Cook Islands in the central South Pacific, north to Micronesia, and south to New Zealand, but excluding New Guinea.

Hodgson, Bryan. "Antarctica: A Land of Isolation No More." *National Geographic* 177, no. 4 (April, 1990): 2-51. Examination of the scientific research there and the controversies revolving around tourism, mineral exploitation, and water and atmospheric pollution.

Kanze, Edward. *Kangaroo Dreaming: An Australian Wildlife Odyssey.* New York: Random House, 2000. Detailed look, in the form of a travelogue, at the fauna of Australia.

Mueller-Dombois, Dieter, and F. Raymond Fosberg. *Vegetation of the Tropical Pacific Islands.* New York: Springer-Verlag, 1998. Extensive survey of the vegetation of the Pacific Islands, including the island of New Guinea, with illustrations.

Smith, David. *Water in Australia: Resources and Management.* New York: Oxford University Press, 1999. Outlines the nature of the resource, past management practices, policy, and the outlook for the future.

Soper, Tony. *Antarctica: A Guide to the Wildlife.* Old Saybrook, Conn.: Globe Pequot Press, 1997. The storm-tossed Southern Ocean and the inhospitable landscape of Antarctica combine to form one of the last true wildernesses on Earth. They are also home to vast numbers of animals, from the tiny shrimp of the zooplankton to the penguins, albatrosses, seals, and great whales for which this region is famed.

Human Geography

Belich, James. *Making Peoples: A History of the New Zealanders: From Polynesian Settlement to the End of the Nineteenth Century.* Honolulu: University of Hawaii Press, 1997. Account of the active and dynamic Maori engagement with the history of New Zealand both before and after British settlement.

Darien-Smith, Kate, and David Lowe. *The Australian Outback and Its People.* Orlando, Fla.: Raintree Steck-Vaughn, 1995. The large, dry regions of Australia, known as the outback, are introduced through brief, slight discussions of their history, environment, inhabitants, and future. The aboriginal culture and the European impact on it are explored at greater length.

Lindstrom, Lamont, and Geoffrey M. White. *Culture, Custom and Tradition: Cultural Policy in Melanesia.* Suva, Fiji: Institute of Pacific Studies, 1994. Looks broadly at cultural development programs and policies in three Melanesian countries: Papua New Guinea, Solomon Islands, and Vanuatu. With more than a thousand distinct linguistic-cultural groups, Melanesia is the most culturally diverse area in the world. Local and national attempts to protect and promote this rich concentration of cultural traditions have produced some novel experiments in cultural development.

New Politics in the South Pacific. Suva, Fiji: Institute of Pacific Studies, 1994. Written almost entirely by Pacific Islanders, many of whom are active in the political process, this volume examines the evolving impact of women in politics, of electronic media, of sovereignty movements on one hand and federation movements on the other. It also examines the search for forms of political and constitutional association between small countries and large metropolitan powers that yield both the dignity of independence and the security and diversity of belonging to large systems.

Nile, Richard, and Christian Clerk. *Australia, New Zealand, and the South Pacific.* New York: Facts on File, 1996. Taking migration as one of its themes, this Atlas traces the great movements of people into this region from earliest times. It describes the complex societies and cultures that evolved in the Pacific and explores the cultural differences between the three major cultural areas, Melanesia, Micronesia, and Polynesia. It also examines the founding myths that shaped Australia and New Zealand's emergent national identities and looks at the great changes that have taken place since 1945.

Economic Geography

King, Michael G. *Fisheries in the Economy of the South Pacific.* Suva, Fiji: Institute of Pacific Studies, 1991. Describes resources, methods, and management of fisheries in the South Pacific.

May, Dawn. *Aboriginal Labour and the Cattle Industry: Queensland from White*

Settlement to the Present. New York: Cambridge University Press, 1994. Uncovers the central role of Aboriginal labor in the Queensland cattle industry from first contact to the present. It shows that the use of Aboriginal labor was a complex process involving a high degree of state intervention.

Regional Geography

McKnight, Tom L. *Oceania: The Geography of Australia, New Zealand and the Pacific Islands.* Upper Saddle River, N.J.: Prentice Hall, 1998. Introduces the geography of the Pacific region in broad terms, then focuses on Australia, blending in discussion of the industries, population, contemporary issues, and problems as they relate to geography. New Zealand's land, people, and regions are discussed next, and the smaller islands of the Pacific receive one chapter's discussion.

Dana P. McDermott

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APPENDICES

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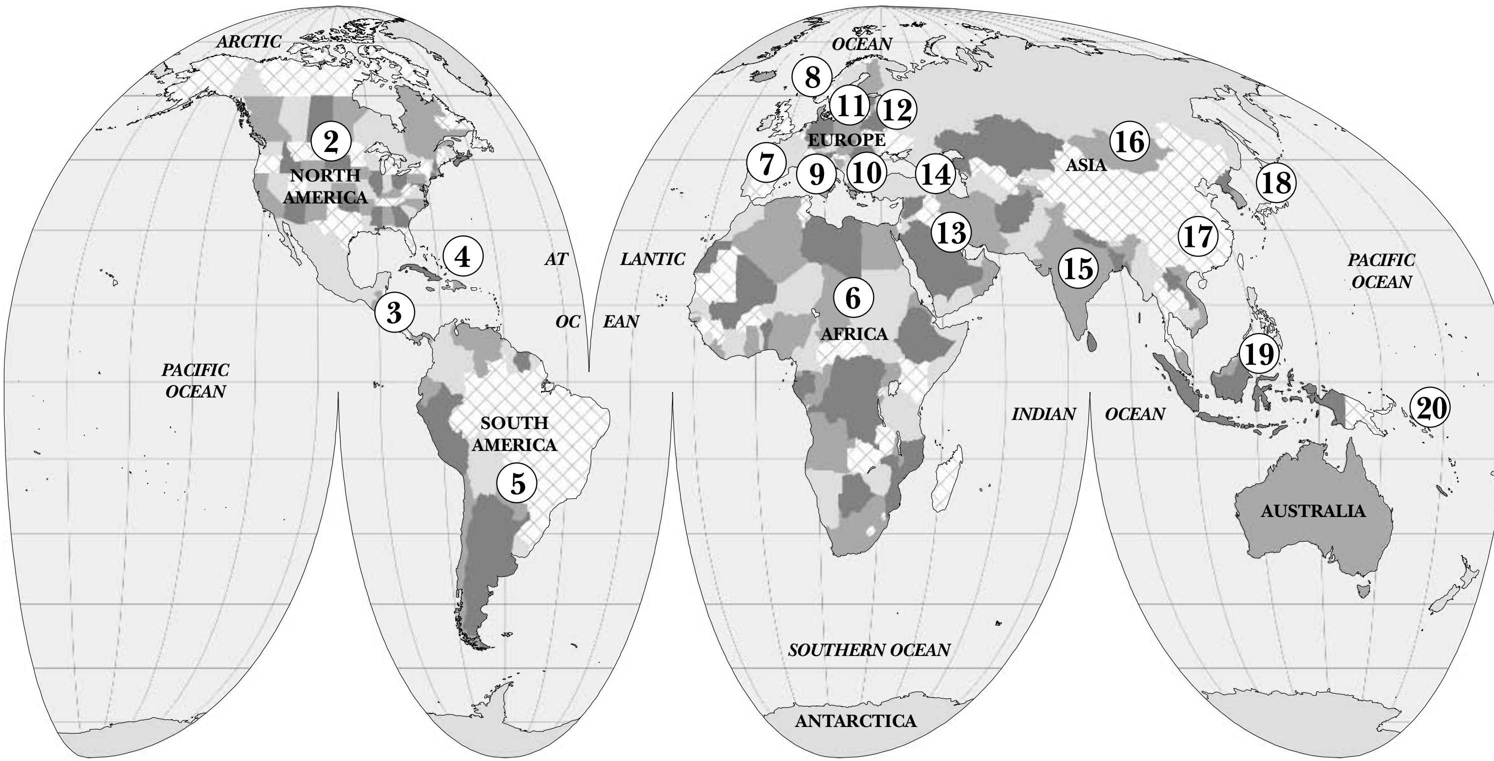
1. Regions of the World

(Numbers are keyed to regional maps that follow.)



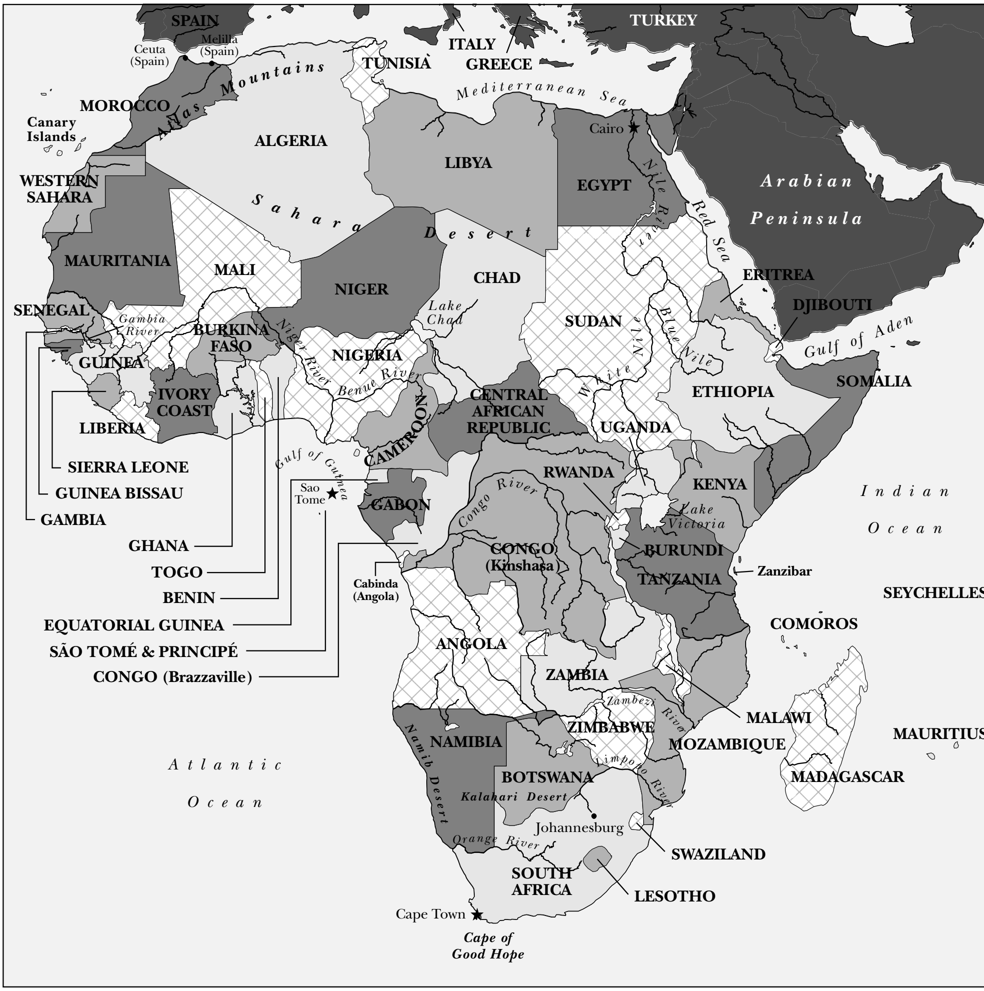
2. North America

3. Central America

4. Caribbean

5. South America

6. Africa


SPAIN
Ceuta (Spain)
Melilla (Spain)
ITALY
GREECE
TURKEY
TUNISIA
Mediterranean Sea
Atlas Mountains
MOROCCO
Canary Islands
ALGERIA
LIBYA
EGYPT
Cairo
WESTERN SAHARA
Sahara Desert
Nile River
Red Sea
Arabian Peninsula
MAURITANIA
MALI
NIGER
CHAD
SUDAN
ERITREA
DJIBOUTI
Gulf of Aden
SENEGAL
Gambia River
BURKINA FASO
Lake Chad
Niger River
Blue Nile
NIGERIA
Benue River
GUINEA
IVORY COAST
LIBERIA
CENTRAL AFRICAN REPUBLIC
White Nile
ETHIOPIA
SOMALIA
UGANDA
CAMEROON
Gulf of Guinea
SIERRA LEONE
GUINEA BISSAU
GAMBIA
Sao Tome
GABON
RWANDA
Congo River
KENYA
Lake Victoria
Indian Ocean
GHANA
TOGO
BENIN
EQUATORIAL GUINEA
SÃO TOMÉ & PRINCIPÉ
CONGO (Brazzaville)
Cabinda (Angola)
CONGO (Kinshasa)
BURUNDI
TANZANIA
Zanzibar
SEYCHELLES
COMOROS
ANGOLA
ZAMBIA
Zambezi River
MALAWI
ZIMBABWE
MOZAMBIQUE
MAURITIUS
NAMIBIA
Namib Desert
BOTSWANA
Kalahari Desert
Limpopo River
MADAGASCAR
Atlantic Ocean
Johannesburg
Orange River
SWAZILAND
SOUTH AFRICA
LESOTHO
Cape Town
Cape of Good Hope

7. Western Europe

8. Scandinavia

9. Mediterranean Europe

10. Balkan Nations

11. Central Europe

12. Former Soviet European Nations

13. Middle East

14. Caucasus and Former Soviet Republics of Central Asia

15. South Asia

16. Mongolia and Asian Russia

17. East Asia

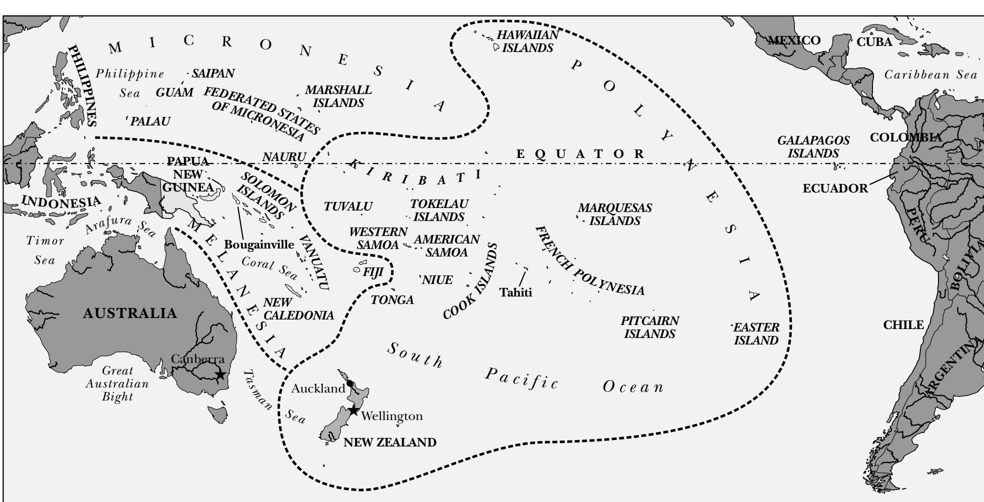

RUSSIA
KAZAKHSTAN
Ulaan baatar
MONGOLIA
Manchuria
Inner Mongolia
Jilin
KYRGYZSTAN
Yining
Hami
Pyongyang
NORTH KOREA
AFG.
Beijing
Tianjin
Seoul
PAK.
SOUTH KOREA
CHINA
Qingdao
Yellow Sea
Xi'an
Nanjing
Shanghai
Tibet
Chengdu
Lhasa
Wenzhon
East China Sea
NEPAL
Nanchang
BHUTAN
Taipei
INDIA
TAIWAN
BANGLADESH
Guangzhou (Canton)
Nanning
Hong Kong
Macao
MYANMAR
VIETNAM
Haikou
LAOS
Bay of Bengal
South China Sea
THAILAND
PHILIPPINES

18. Japan


CHINA
RUSSIA
NORTH KOREA
SOUTH KOREA
Kuril Islands
HOKKAIDO
Sapporo
Sea of Japan
North Pacific Ocean
JAPAN
HONSHU
Tokyo
Kyoto
Nagoya
Kobe
Hiroshima
Yokohama
Osaka
SHIKOKU
Nagasaki
KYUSHU
East China Sea
Ryukyu Islands
Okinawa

19. Southeast Asia

20. South Pacific And Australasia



The World's Oceans and Seas

Name	Approximate Area: Sq. Miles	Approximate Area: Sq. Km.	Average Depth: Feet	Average Depth: Meters
Pacific Ocean	64,000,000	165,760,000	13,215	4,028
Atlantic Ocean	31,815,000	82,400,000	12,880	3,926
Indian Ocean	25,300,000	65,526,700	13,002	3,963
Arctic Ocean	5,440,200	14,090,000	3,953	1,205
Mediterranean and Black Seas	1,145,100	2,965,800	4,688	1,429
Caribbean Sea	1,049,500	2,718,200	8,685	2,647
South China Sea	895,400	2,319,000	5,419	1,652
Bering Sea	884,900	2,291,900	5,075	1,547
Gulf of Mexico	615,000	1,592,800	4,874	1,486
Okhotsk Sea	613,800	1,589,700	2,749	838
East China Sea	482,300	1,249,200	617	188
Hudson Bay	475,800	1,232,300	420	128
Japan Sea	389,100	1,007,800	4,429	1,350
Andaman Sea	308,100	797,700	2,854	870
North Sea	222,100	575,200	308	94
Red Sea	169,100	438,000	1,611	491
Baltic Sea	163,000	422,200	180	55

Major Land Areas of the World

Area	Approximate Land Area: Sq. Mi.	Approximate Land Area: Sq. Km.	Portion of World Total
World	57,308,738	148,429,000	100.0%
Asia (including Middle East)	17,212,041	44,579,000	30.0
Africa	11,608,156	30,065,000	20.3
North America	9,365,290	24,256,000	16.3
Central America, South America, and Caribbean	6,879,952	17,819,000	8.9
Antarctica	5,100,021	13,209,000	8.9
Europe	3,837,082	9,938,000	6.7
Oceania, including Australia	2,967,966	7,687,000	5.2

Major Islands of the World

		Area	
Island	*Location*	*Sq. Mi.*	*Sq. Km*
Greenland	North Atlantic Ocean	839,999	2,175,597
New Guinea	Western Pacific Ocean	316,615	820,033
Borneo	Western Pacific Ocean	286,914	743,107
Madagascar	Western Indian Ocean	226,657	587,042
Baffin	Canada, North Atlantic Ocean	183,810	476,068
Sumatra	Indonesia, northeast Indian Ocean	182,859	473,605
Hōnshū	Japan, western Pacific Ocean	88,925	230,316
Great Britain	North Atlantic Ocean	88,758	229,883
Ellesmere	Canada, Arctic Ocean	82,119	212,688
Victoria	Canada, Arctic Ocean	81,930	212,199
Sulawesi (Celebes)	Indonesia, western Pacific Ocean	72,986	189,034
South Island	New Zealand, South Pacific Ocean	58,093	150,461
Java	Indonesia, Indian Ocean	48,990	126,884
North Island	New Zealand, South Pacific Ocean	44,281	114,688
Cuba	Caribbean Sea	44,218	114,525
Newfoundland	Canada, North Atlantic Ocean	42,734	110,681
Luzon	Philippines, western Pacific Ocean	40,420	104,688
Iceland	North Atlantic Ocean	39,768	102,999
Mindanao	Philippines, western Pacific Ocean	36,537	94,631
Ireland	North Atlantic Ocean	32,597	84,426
Hokkaido	Japan, western Pacific Ocean	30,372	78,663
Hispaniola	Caribbean Sea	29,355	76,029
Tasmania	Australia, South Pacific Ocean	26,215	67,897
Sri Lanka	Indian Ocean	25,332	65,610
Sakhalin (Karafuto)	Russia, western Pacific Ocean	24,560	63,610
Banks	Canada, Arctic Ocean	23,230	60,166
Devon	Canada, Arctic Ocean	20,861	54,030
Tierra del Fuego	Southern tip of South America	18,605	48,187
Kyūshū	Japan, western Pacific Ocean	16,223	42,018
Melville	Canada, Arctic Ocean	16,141	41,805
Axel Heiberg	Canada, Arctic Ocean	15,779	40,868
Southampton	Hudson Bay, Canada	15,700	40,663

Countries of the World

Country	Map	Region	Population	Area: Square Miles	Area: Square Kilometers
Afghanistan	15	Asia	28,717,213	249,935	647,500
Albania	10	Europe	3,582,205	11,098	28,750
Algeria	6	Africa	32,818,500	919,352	2,381,740
Andorra	7	Europe	69,150	174	450
Angola	6	Africa	10,766,471	481,226	1,246,700
Antigua and Barbuda	4	Caribbean	67,897	170	440
Argentina	5	South America	38,740,807	1,068,020	2,766,890
Armenia	14	Europe	3,326,448	11,503	29,800
Australia	20	Australia	19,731,984	2,967,124	7,686,850
Austria	7	Europe	8,188,207	32,369	83,858
Azerbaijan	14	Asia	7,830,764	33,428	86,600
Bahamas	4	Caribbean	297,477	5,381	13,940
Bahrain	13	Asia	667,238	239	620
Bangladesh	15	Asia	138,448,210	55,584	144,000
Barbados	4	Caribbean	277,264	166	430
Belarus	12	Europe	10,322,151	80,134	207,600
Belgium	7	Europe	10,289,088	11,777	30,510
Belize	3	Central America	266,440	8,863	22,960
Benin	6	Africa	7,041,490	43,471	112,620
Bhutan	15	Asia	2,139,549	18,142	47,000
Bolivia	5	South America	8,586,443	424,052	1,098,580
Bosnia and Herzegovina	10	Europe	3,989,018	19,776	51,233
Botswana	6	Africa	1,573,267	231,743	600,370
Brazil	5	South America	182,032,604	3,285,618	8,511,965
Brunei	13	Asia	358,098	2,227	5,770
Bulgaria	10	Europe	7,537,929	42,811	110,910
Burkina Faso	6	Africa	13,228,460	105,841	274,200
Burundi	6	Africa	6,096,156	10,742	27,830

Country	Map	Region	Population	Area: Square Miles	Area: Square Kilometers
Cambodia	19	Asia	13,124,764	69,881	181,040
Cameroon	6	Africa	15,746,179	183,520	475,440
Canada	2	North America	32,207,113	3,850,790	9,976,140
Cape Verde	6	Africa	412,137	1,556	4,030
Central African Republic	6	Africa	3,683,538	240,470	622,980
Chad	6	Africa	9,253,493	495,624	1,284,000
Chile	5	South America	15,665,216	292,183	756,950
China, People's Republic of	17	Asia	1,286,975,468	3,704,427	9,596,960
Colombia	5	South America	41,662,073	439,619	1,138,910
Comoros	6	Africa	632,948	838	2,170
Congo (Brazzaville)	6	Africa	2,954,258	132,012	342,000
Congo (Kinshasa)	6	Africa	56,625,039	905,328	2,345,410
Costa Rica	3	Central America	3,896,092	19,725	51,100
Côte d'Ivoire	6	Africa	16,962,491	124,470	322,460
Croatia	10	Europe	4,422,248	21,824	56,538
Cuba	4	Caribbean	11,263,429	42,792	110,860
Cyprus	9	Europe	771,657	3,571	9,250
Czech Republic	11	Europe	10,249,216	30,379	78,703
Denmark	8	Europe	5,384,384	16,634	43,094
Djibouti	6	Africa	457,130	8,492	22,000
Dominica	4	Caribbean	69,655	290	750
Dominican Republic	4	Caribbean	8,715,602	18,810	48,730
East Timor	19	Asia	997,853	7,336	19,000
Ecuador	5	South America	13,710,234	109,454	283,560
Egypt	6	Africa	74,718,797	386,560	1,001,450
El Salvador	3	Central America	6,470,379	8,121	21,040
Equatorial Guinea	6	Africa	510,473	10,827	28,050
Eritrea	6	Africa	4,362,254	46,830	121,320
Estonia	12	Europe	1,408,556	17,457	45,226

(continued)

Countries of the World — *continued*

Country	*Map*	*Region*	*Population*	*Area* Square Miles	*Area* Square Kilometers
Ethiopia	6	Africa	66,557,553	435,071	1,127,127
Fiji	20	Pacific Islands	868,531	7,052	18,270
Finland	8	Europe	5,190,785	130,094	337,030
France	7	Europe	60,180,529	211,154	547,030
Gabon	6	Africa	1,321,560	103,321	267,670
Gambia	6	Africa	1,501,050	4,362	11,300
Georgia	14	Europe	4,934,413	26,904	69,700
Germany	7	Europe	82,398,326	137,767	356,910
Ghana	6	Africa	20,467,747	92,076	238,540
Greece	9	Europe	10,665,989	50,929	131,940
Grenada	4	Caribbean	89,258	131	340
Guam	20	Pacific Islands	163,941	212	549
Guatemala	3	Central America	13,909,384	42,032	108,890
Guinea	6	Africa	9,030,220	94,902	245,860
Guinea-Bissau	6	Africa	1,360,827	13,942	36,120
Guyana	5	South America	702,100	82,978	214,970
Haiti	4	Caribbean	7,527,817	10,712	27,750
Honduras	3	Central America	6,669,789	43,267	112,090
Hungary	11	Europe	10,045,407	35,910	93,030
Iceland	8	Europe	280,798	39,758	103,000
India	15	Asia	1,049,700,118	1,269,010	3,287,590
Indonesia	19	Asia	234,893,453	740,904	1,919,440
Iran	13	Asia	68,278,826	636,128	1,648,000
Iraq	13	Asia	24,683,313	168,710	437,072
Ireland	7	Europe	3,924,140	27,128	70,280
Israel	13	Asia	6,116,533	8,017	20,770
Italy	9	Europe	57,998,353	116,275	301,230
Jamaica	4	Caribbean	2,695,867	4,242	10,990
Japan	18	Asia	127,214,499	145,844	377,835
Jordan	13	Asia	5,460,265	34,436	89,213

Country	Map	Region	Population	Area: Square Miles	Area: Square Kilometers
Kazakhstan	14	Asia	16,763,795	1,048,878	2,717,300
Kenya	6	Africa	31,639,091	224,903	582,650
Kiribati	20	Pacific Islands	98,549	277	717
Korea, North	17	Asia	22,466,481	46,528	120,540
Korea, South	17	Asia	48,289,037	38,013	98,480
Kuwait	13	Asia	2,183,161	6,879	17,820
Kyrgyzstan	14	Asia	4,892,808	76,621	198,500
Laos	19	Asia	5,921,545	91,405	236,800
Latvia	12	Europe	2,348,784	24,743	64,100
Lebanon	13	Asia	3,727,703	4,014	10,400
Lesotho	6	Africa	1,861,959	11,715	30,350
Liberia	6	Africa	3,317,176	42,989	111,370
Libya	6	Africa	5,499,074	679,182	1,759,540
Liechtenstein	7	Europe	33,145	62	160
Lithuania	12	Europe	3,592,561	25,167	65,200
Luxembourg	7	Europe	454,157	998	2,586
Macedonia	10	Europe	2,063,122	9,779	25,333
Madagascar	6	Africa	16,979,744	226,597	587,040
Malawi	6	Africa	11,651,239	45,733	118,480
Malaysia	19	Asia	23,092,940	127,284	329,750
Maldives	15	Asia	329,684	116	300
Mali	6	Africa	11,626,219	478,640	1,240,000
Malta	9	Europe	400,420	124	320
Marshall Islands	20	Pacific Islands	56,429	70	181.3
Martinique	4	Caribbean	425,966	425	1,100
Mauritania	6	Africa	2,912,584	397,850	1,030,700
Mauritius	6	Africa	1,210,447	718	1,860
Mexico	2	North America	104,907,991	761,404	1,972,550
Micronesia	20	Pacific Islands	136,973	271	702
Moldova	12	Europe	4,439,502	13,008	33,700

(continued)

COUNTRIES OF THE WORLD — *continued*

Country	*Map*	*Region*	*Population*	*Area* Square Miles	Square Kilometers
Monaco	7	Europe	32,130	1	1.95
Mongolia	16, 17	Asia	2,712,315	604,090	1,565,000
Morocco	6	Africa	31,689,265	172,368	446,550
Mozambique	6	Africa	17,479,266	309,414	801,590
Myanmar (Burma)	15, 19	Asia	42,510,537	261,901	678,500
Namibia	6	Africa	1,927,447	318,611	825,418
Nauru	20	Pacific Islands	12,570	8	21
Nepal	15	Asia	26,469,569	54,349	140,800
Netherlands	7	Europe	16,150,511	16,029	41,526
New Zealand	20	Pacific Islands	3,951,307	103,710	268,680
Nicaragua	3	Central America	5,128,517	49,985	129,494
Niger	6	Africa	11,058,590	489,062	1,267,000
Nigeria	6	Africa	133,881,703	356,575	923,770
Norway	8	Europe	4,546,123	125,149	324,220
Oman	13	Asia	2,807,125	82,010	212,460
Pakistan	15	Asia	150,694,740	310,321	803,940
Palau	20	Pacific Islands	19,717	177	458
Panama	3	Central America	2,960,784	30,185	78,200
Papua New Guinea	20	Pacific Islands	5,295,816	178,212	461,690
Paraguay	5	South America	6,036,900	157,006	406,750
Peru	5	South America	28,409,897	496,095	1,285,220
Philippines	19	Asia	84,619,974	115,800	300,000
Poland	11	Europe	38,622,660	120,696	312,683
Portugal	7, 9	Europe	10,102,022	35,663	92,391
Qatar	13	Asia	817,052	4,415	11,437
Romania	11	Europe	22,271,839	91,675	237,500
Russia	12, 16	Europe/Asia	144,526,278	6,591,027	17,075,200
Rwanda	6	Africa	7,810,056	10,167	26,340
Saint Kitts and Nevis	4	Caribbean	38,763	104	269

Country	Map	Region	Population	Area: Square Miles	Area: Square Kilometers
Saint Lucia	4	Caribbean	162,157	239	620
Saint Vincent and Grenadines	4	Caribbean	116,812	131	340
Samoa	20	Pacific Islands	178,173	1,104	2,860
San Marino	7	Europe	28,119	23	60
São Tomé and Príncipe	6	Africa	175,883	371	960
Saudi Arabia	13	Asia	24,293,844	756,785	1,960,582
Senegal	6	Africa	10,580,307	75,729	196,190
Seychelles	6	Africa	80,469	176	455
Sierra Leone	6	Africa	5,732,681	27,692	71,740
Singapore	19	Asia	4,608,595	250	647.5
Slovakia	11	Europe	5,430,033	18,854	48,845
Slovenia	10	Europe	1,935,677	7,819	20,256
Solomon Islands	20	Pacific Islands	509,190	10,982	28,450
Somalia	6	Africa	8,025,190	246,137	637,660
South Africa	6	Africa	42,768,678	470,886	1,219,912
Spain	7, 9	Europe	40,217,413	194,834	504,750
Sri Lanka	15	Asia	19,742,439	25,325	65,610
Sudan	6	Africa	38,114,160	967,243	2,505,810
Suriname	5	South America	435,449	63,022	163,270
Swaziland	6	Africa	1,161,219	6,701	17,360
Sweden	8	Europe	8,878,085	173,686	449,964
Switzerland	7	Europe	7,318,638	15,938	41,290
Syria	13	Asia	17,585,540	71,479	185,180
Taiwan	17	Asia	22,603,000	13,888	35,980
Tajikistan	14	Asia	6,863,752	55,237	143,100
Tanzania	6	Africa	35,922,454	364,805	945,090
Thailand	19	Asia	64,265,276	198,404	514,000
Togo	6	Africa	5,429,299	21,921	56,790
Tonga	20	Pacific Islands	108,141	289	748

(continued)

COUNTRIES OF THE WORLD — *continued*

Country	Map	Region	Population	Area: Square Miles	Area: Square Kilometers
Trinidad and Tobago	4	Caribbean	1,104,209	1,980	5,130
Tunisia	6	Africa	9,924,742	63,153	163,610
Turkey	13	Europe/Asia	68,109,469	301,304	780,580
Turkmenistan	14	Asia	4,775,544	188,407	488,100
Tuvalu	20	Pacific Islands	11,305	10	26
Uganda	6	Africa	25,632,794	91,111	236,040
Ukraine	12	Europe	48,055,439	233,028	603,700
United Arab Emirates	13	Asia	2,484,818	31,992	82,880
United Kingdom	7	Europe	60,094,648	94,501	244,820
United States	2	North America	290,342,554	3,716,829	9,629,091
Uruguay	5	South America	3,413,329	68,021	176,220
Uzbekistan	14	Asia	25,981,647	172,696	447,400
Vanuatu	20	Pacific Islands	199,414	5,697	14,760
Vatican City	9	Europe	900	0.2	.44
Venezuela	5	South America	24,654,694	352,051	912,050
Vietnam	19	Asia	81,624,716	127,210	329,560
Western Sahara	6	Africa	261,794	102,676	266,000
Yemen	13	Asia	19,349,881	203,796	527,970
Yugoslavia	10	Europe	10,655,774	39,507	102,350
Zambia	6	Africa	10,307,333	290,507	752,610
Zimbabwe	6	Africa	12,576,742	150,764	390,580

Note: Population figures are October, 2002, estimates.
Source: U.S. Census Bureau, International Data Base.

THE WORLD'S LARGEST COUNTRIES BY AREA

			Area	
Rank	*Country*	*Region*	*Sq. Miles*	*Sq. Km.*
1	Russia	Europe/Asia	6,591,027	17,075,200
2	Canada	North America	3,850,790	9,976,140
3	United States	North America	3,716,829	9,629,091
4	China, People's Republic of	Asia	3,704,427	9,596,960
5	Brazil	South America	3,285,618	8,511,965
6	Australia	Australia	2,967,124	7,686,850
7	India	Asia	1,269,010	3,287,590
8	Argentina	South America	1,068,020	2,766,890
9	Kazakhstan	Asia	1,048,878	2,717,300
10	Sudan	Africa	967,243	2,505,810
11	Algeria	Africa	919,352	2,381,740
12	Congo (Kinshasa)	Africa	905,328	2,345,410
13	Mexico	North America	761,404	1,972,550
14	Saudi Arabia	Asia	756,785	1,960,582
15	Indonesia	Asia	740,904	1,919,440
16	Libya	Africa	679,182	1,759,540
17	Iran	Asia	636,128	1,648,000
18	Mongolia	Asia	604,090	1,565,000
19	Peru	South America	496,095	1,285,220
20	Chad	Africa	495,624	1,284,000
21	Niger	Africa	489,062	1,267,000
22	Angola	Africa	481,226	1,246,700
23	Mali	Africa	478,640	1,240,000
24	South Africa	Africa	470,886	1,219,912
25	Colombia	South America	439,619	1,138,910
26	Ethiopia	Africa	435,071	1,127,127
27	Bolivia	South America	424,052	1,098,580
28	Mauritania	Africa	397,850	1,030,700
29	Egypt	Africa	386,560	1,001,450
30	Tanzania	Africa	364,805	945,090

Source: U.S. Census Bureau, International Data Base.

The World's Smallest Countries by Area

Rank	Country	Region	Area Sq. Miles	Area Sq. Km.
1	Vatican City*	Europe	0.2	.44
2	Monaco*	Europe	1	1.95
3	Nauru	Pacific Islands	8	21
4	Tuvalu	Pacific Islands	10	26
5	San Marino*	Europe	23	60
6	Liechtenstein*	Europe	62	160
7	Marshall Islands	Pacific Islands	70	181.3
8	Saint Kitts and Nevis	Caribbean	104	269
9	Maldives	Asia	116	300
10	Malta	Europe	124	320
11	Grenada	Caribbean	131	340
12	Saint Vincent and Grenadines	Caribbean	131	340
13	Barbados	Caribbean	166	430
14	Antigua and Barbuda	Caribbean	170	440
15	Andorra*	Europe	174	450
16	Seychelles	Africa	176	455
17	Palau	Pacific Islands	177	458
18	Guam	Pacific Islands	212	549
19	Bahrain	Asia	239	620
20	Saint Lucia	Caribbean	239	620
21	Singapore*	Asia	250	647.5
22	Micronesia	Pacific Islands	271	702
23	Kiribati	Pacific Islands	277	717
24	Tonga	Pacific Islands	289	748
25	Dominica	Caribbean	290	750
26	São Tomé and Príncipe	Africa	371	960
27	Martinique	Caribbean	425	1,100
28	Mauritius	Africa	718	1,860
29	Comoros	Africa	838	2,170
30	Luxembourg*	Europe	998	2,586

Note: Asterisks (*) denote countries on continents; all other countries are islands or island groups.
Source: U.S. Census Bureau, International Data Base.

The World's Largest Countries by Population

Rank	*Country*	*Region*	*Population*
1	China	Asia	1,286,975,468
2	India	Asia	1,049,700,118
3	United States	North America	290,342,554
4	Indonesia	Asia	234,893,453
5	Brazil	South America	182,032,604
6	Pakistan	Asia	150,694,740
7	Russia	Europe/Asia	144,526,278
8	Bangladesh	Asia	138,448,210
9	Nigeria	Africa	133,881,703
10	Japan	Asia	127,214,499
11	Mexico	North America	104,907,991
12	Philippines	Asia	84,619,974
13	Germany	Europe	82,398,326
14	Vietnam	Asia	81,624,716
15	Egypt	Africa	74,718,797
16	Iran	Asia	68,278,826
17	Turkey	Europe/Asia	68,109,469
18	Ethiopia	Africa	66,557,553
19	Thailand	Asia	64,265,276
20	France	Europe	60,180,529
21	United Kingdom	Europe	60,094,648
22	Italy	Europe	57,998,353
23	Congo (Kinshasa)	Africa	56,625,039
24	Korea, South	Asia	48,289,037
25	Ukraine	Asia	48,055,439
26	South Africa	Africa	42,768,678
27	Mayanmar (Burma)	Asia	42,510,537
28	Colombia	South America	41,662,073
29	Spain	Europe	40,217,413
30	Argentina	South America	38,740,807

Source: U.S. Census Bureau, International Data Base. Updated October 10, 2002.

The World's Smallest Countries by Population

Rank	*Country*	*Region*	*Population*
1	Vatican City	Europe	900
2	Tuvalu	Pacific Islands	11,305
3	Nauru	Pacific Islands	12,570
4	Palau	Pacific Islands	19,717
5	San Marino	Europe	28,119
6	Monaco	Europe	32,130
7	Liechtenstein	Europe	33,145
8	Saint Kitts and Nevis	Caribbean	38,763
9	Marshall Islands	Pacific Islands	56,429
10	Antigua and Barbuda	Caribbean	67,897
11	Andorra	Europe	69,150
12	Dominica	Caribbean	69,655
13	Seychelles	Africa	80,469
14	Grenada	Caribbean	89,258
15	Kiribati	Pacific Islands	98,549
16	Tonga	Pacific Islands	108,141
17	Saint Vincent and the Grenadines	Caribbean	116,812
18	Micronesia	Pacific Islands	136,973
19	Saint Lucia	Caribbean	162,157
20	Guam	Pacific Islands	163,941
21	São Tome and Principe	Africa	175,883
22	Samoa	Pacific Islands	178,173
23	Vanuatu	Pacific Islands	199,414
24	Western Sahara	Africa	261,794
25	Belize	Central America	266,440
26	Barbados	Caribbean	277,264
27	Iceland	Europe	280,798
28	Bahamas	Caribbean	297,477
29	Maldives	Asia	329,684
30	Brunei	Asia	358,098

Note: Population figures are October, 2002, estimates.
Source: U.S. Census Bureau, International Data Base.

The World's Most Densely Populated Countries

			Persons per square	
Rank	*Country*	*Region*	*Mile*	*Kilometer*
1	Monaco	Europe	41,423.2	15,993.5
2	Singapore	Asia	18,481.7	7,135.8
3	Vatican City	Europe	5,698.0	2,200.0
4	Malta	Europe	3,207.2	1,238.3
5	Maldives	Asia	2,764.0	1,067.2
6	Bahrain	Asia	2,746.4	1,060.4
7	Bangladesh	Asia	2,579.6	996.0
8	Taiwan	Asia	1,810.2	698.9
9	Mauritius	Africa	1,681.2	649.1
10	Barbados	Caribbean	1,666.1	643.3

Note: Based on October, 2002, population estimates.
Source: U.S. Census Bureau, U.S. Department of Commerce.

The World's Least Densely Populated Countries

			Persons per square	
Rank	*Country*	*Region*	*Mile*	*Kilometer*
1	Mongolia	Asia	4.4	1.7
2	Namibia	Africa	5.7	2.2
3	Australia	Australasia	6.7	2.6
4	Suriname	South America	7.0	2.7
5	Botswana	Africa	7.0	2.7
6	Mauritania	Africa	7.0	2.7
7	Iceland	Europe	7.3	2.8
8	Libya	Africa	8.0	3.1
9	Guyana	South America	9.1	3.5
10	Canada	North America	9.1	3.5

Note: Based on October, 2002, population estimates.
Source: U.S. Census Bureau, U.S. Department of Commerce.

The World's Most Populous Cities

Rank	*City*	*Country*	*Region*	*Population*
1	Seoul	South Korea	East Asia	10,231,217
2	São Paulo	Brazil	South America	10,017,821
3	Mumbai (Bombay)	India	Asia	9,925,891
4	Jakarta	Indonesia	Asia	9,112,652
5	Moscow	Russia	Europe	8,368,449
6	Istanbul	Turkey	Europe	8,274,921
7	Mexico City	Mexico	North America	8,235,744
8	Shanghai	China	Asia	8,214,384
9	Tokyo	Japan	Asia	7,967,614
10	New York City	United States	North America	7,380,906
11	Beijing	China	Asia	7,362,426
12	Delhi	India	Asia	7,206,704
13	London	Great Britain	Europe	7,074,265
14	Cairo	Egypt	Africa	6,800,000
15	Teheran	Iran	Asia	6,750,043
16	Hong Kong	China	Asia	6,502,000
17	Bangkok	Thailand	Asia	5,882,000
18	Tianjin	China	Asia	5,855,044
19	Lima	Peru	South America	5,681,941
20	Rio de Janeiro	Brazil	South America	5,606,497
21	Bogotá	Colombia	South America	4,945,448
22	Shenyang	China	Asia	4,669,737
23	Santiago	Chile	South America	4,640,635
24	Kolkata (Calcutta)	India	Asia	4,399,819
25	St. Petersburg	Russia	Europe	4,232,105
26	Wuhan	China	Asia	4,040,113
27	Guangzhou	China	Asia	3,935,193
28	Chennai (Madras)	India	Asia	3,841,396
29	Baghdad	Iraq	Asia	3,841,268
30	Pusan	South Korea	Asia	3,814,325

Note: Population figures are for latest available years and are for defined cities. The metropolitan areas of most of these cities are much larger.

Source: 1997 Demographic Yearbook, United Nations.

Major Lakes of the World

		Surface Area		*Maximum Depth*	
Lake	*Location*	*Sq. Mi.*	*Sq. Km*	*Feet*	*Meters*
Caspian Sea	Central Asia	152,239	394,299	3,104	946
Superior	North America	31,820	82,414	1,333	406
Victoria	East Africa	26,828	69,485	270	82
Huron	North America	23,010	59,596	750	229
Michigan	North America	22,400	58,016	923	281
Aral	Central Asia	13,000	33,800	223	68
Tanganyika	East Africa	12,700	32,893	4,708	1,435
Baikal	Russia	12,162	31,500	5,712	1,741
Great Bear	North America	12,000	31,080	270	82
Nyasa	East Africa	11,600	30,044	2,316	706
Great Slave	North America	11,170	28,930	2,015	614
Chad	West Africa	9,946	25,760	23	7
Erie	North America	9,930	25,719	210	64
Winnipeg	North America	9,094	23,553	204	62
Ontario	North America	7,520	19,477	778	237
Balkhash	Central Asia	7,115	18,428	87	27
Ladoga	Russia	7,000	18,130	738	225
Onega	Russia	3,819	9,891	361	110
Titicaca	South America	3,141	8,135	1,214	370
Nicaragua	Central America	3,089	8,001	230	70
Athabaska	North America	3,058	7,920	407	124
Rudolf	Kenya, East Africa	2,473	6,405	240	73
Reindeer	North America	2,444	6,330	720	220
Eyre	South Australia	2,400	6,216	varies	varies
Issyk-Kul	Central Asia	2,394	6,200	2,297	700
Urmia	Southwest Asia	2,317	6,001	49	15
Torrens	Australia	2,200	5,698	—	—
Vänern	Sweden	2,141	5,545	322	98
Winnipegosis	North America	2,086	5,403	59	18
Mobutu Sese Seko	East Africa	2,046	5,299	180	55
Nettilling	North America	1,950	5,051	—	—

Note: The sizes of some lakes vary with the seasons.

Major Rivers of the World

River	*Region*	*Outflow*	*Approximate Length*	
			Miles	*Km.*
Nile	North Africa	Mediterranean Sea	4,180	6,690
Mississippi-Missouri-Red Rock	North America	Gulf of Mexico	3,710	5,970
Yangtze Kiang	East Asia	China Sea	3,602	5,797
Ob	Russia	Gulf of Ob	3,459	5,567
Yellow (Huang He)	East Asia	Gulf of Chihli	2,900	4,667
Yenisei	Russia	Arctic Ocean	2,800	4,506
Paraná	South America	Río de la Plata	2,795	4,498
Irtish	Russia	Ob River	2,758	4,438
Congo	Africa	Atlantic Ocean	2,716	4,371
Heilong (Amur)	East Asia	Tatar Strait	2,704	4,352
Lena	Russia	Arctic Ocean	2,652	4,268
Mackenzie	North America	Beaufort Sea	2,635	4,241
Niger	West Africa	Gulf of Guinea	2,600	4,184
Mekong	Asia	South China Sea	2,500	4,023
Mississippi	North America	Gulf of Mexico	2,348	3,779
Missouri	North America	Mississippi River	2,315	3,726
Volga	Russia	Caspian Sea	2,291	3,687
Madeira	South America	Amazon River	2,012	3,238
Purus	South America	Amazon River	1,993	3,207
São Francisco	South America	Atlantic Ocean	1,987	3,198
Yukon	North America	Bering Sea	1,979	3,185
St. Lawrence	North America	Gulf of St. Lawrence	1,900	3,058
Rio Grande	North America	Gulf of Mexico	1,885	3,034
Brahmaputra	Asia	Ganges River	1,800	2,897
Indus	Asia	Arabian Sea	1,800	2,897
Danube	Europe	Black Sea	1,766	2,842

River	Region	Outflow	Approximate Length Miles	Approximate Length Km.
Euphrates	Asia	Shatt-al-Arab	1,739	2,799
Darling	Australia	Murray River	1,702	2,739
Zambezi	Africa	Mozambique Channel	1,700	2,736
Tocantins	South America	Pará River	1,677	2,699
Murray	Australia	Indian Ocean	1,609	2,589
Nelson	North America	Hudson Bay	1,600	2,575
Paraguay	South America	Paraná River	1,584	2,549
Ural	Russia	Caspian Sea	1,574	2,533
Ganges	Asia	Bay of Bengal	1,557	2,506
Amu Darya (Oxus)	Asia	Aral Sea	1,500	2,414
Japurá	South America	Amazon River	1,500	2,414
Salween	Asia	Gulf of Martaban	1,500	2,414
Arkansas	North America	Mississippi River	1,459	2,348
Colorado	North America	Gulf of California	1,450	2,333
Dnieper	Russia	Black Sea	1,419	2,284
Ohio-Allegheny	North America	Mississippi River	1,306	2,102
Irrawaddy	Asia	Bay of Bengal	1,300	2,092
Orange	Africa	Atlantic Ocean	1,300	2,092
Orinoco	South America	Atlantic Ocean	1,281	2,062
Pilcomayo	South America	Paraguay River	1,242	1,999
Xi Jiang	East Asia	China Sea	1,236	1,989
Columbia	North America	Pacific Ocean	1,232	1,983
Don	Russia	Sea of Azov	1,223	1,968
Sungari	East Asia	Amur River	1,215	1,955
Saskatchewan	North America	Lake Winnipeg	1,205	1,939
Peace	North America	Great Slave River	1,195	1,923
Tigris	Asia	Shatt-al-Arab	1,180	1,899

The Highest Peaks in Each Continent

			Height	
Continent	*Mountain*	*Location*	*Feet*	*Meters*
Asia	Everest	Tibet & Nepal	29,028	8,848
South America	Aconcagua	Argentina	22,834	6,960
North America	McKinley	Alaska	20,320	6,194
Africa	Kilimanjaro	Tanzania	19,340	5,895
Europe	Elbrus	Russia & Georgia	18,510	5,642
Antarctica	Vinson Massif	Ellsworth Mountains	16,066	4,897
Australia	Kosciusko	New South Wales	7,316	2,228

Note: The world's highest sixty-six mountains are all in Asia.

Major Deserts of the World

		Approximate area		
Desert	*Location*	*Sq. miles*	*Sq. km.*	*Type*
Antarctic	Antarctica	5,400,000	14,002,200	polar
Sahara	North Africa	3,500,000	9,075,500	subtropical
Arabian	Southwest Asia	1,000,000	2,593,000	subtropical
Great Western (Gibson, Great Sandy, and Great Victoria)	Australia	520,000	1,348,360	subpical
Gobi	East Asia	500,000	1,296,500	cold winter
Patagonian	Argentina, South America	260,000	674,180	cold winter
Kalahari	Southern Africa	220,000	570,460	subtropical
Great Basin	Western United States	190,000	492,670	cold winter
Thar	South Asia	175,000	453,775	subtropical
Chihuahuan	Mexico	175,000	453,775	subtropical
Karakum	Central Asia	135,000	350,055	cold winter
Colorado Plateau	Southwestern United States	130,000	337,090	cold winter
Sonoran	United States and Mexico	120,000	311,160	subtropical
Kyzylkum	Central Asia	115,000	298,195	cold winter
Taklimakan	China	105,000	272,265	cold winter
Iranian	Iran	100,000	259,300	cold winter
Arctic	Arctic Circle	62,000	161,000	polar
Simpson	Eastern Australia	56,000	145,208	subtropical
Mojave	Western United States	54,000	140,022	subtropical
Atacama	Chile, South America	54,000	140,022	cold coastal
Namib	Southern Africa	13,000	33,709	cold coastal

Highest Waterfalls of the World

Waterfall	Location	Source	Height Feet	Height Meters
Angel	Canaima National Park, Venezuela	Rio Caroni	3,212	979
Tugela	Natal National Park, South Africa	Tugela River	3,110	948
Utigord	Norway	glacier	2,625	800
Monge	Marstein, Norway	Mongebeck	2,540	774
Mutarazi	Nyanga National Park, Zimbabwe	Mutarazi River	2,499	762
Yosemite	Yosemite National Park, California, U.S.	Yosemite Creek	2,425	739
Espelands	Hardanger Fjord, Norway	Opo River	2,307	703
Lower Mar Valley	Eikesdal, Norway	Mardals Stream	2,151	655
Tyssestrengene	Odda, Norway	Tyssa River	2,123	647
Cuquenan	Kukenan Tepuy, Venezuela	Cuquenan River	2,000	610
Sutherland	Milford Sound, New Zealand	Arthur River	1,904	580
Kjell	Gudvanger, Norway	Gudvangen Glacier	1,841	561
Takkakaw	Yoho National Park, British Columbia, Canada	Takkakaw Creek	1,650	503
Ribbon	Yosemite National Park, California, U.S.	Ribbon Stream	1,612	491
Upper Mar Valley	near Eikesdal, Norway	Mardals Stream	1,536	468
Gavarnie	near Lourdes, France	Gave de Pau	1,388	423
Vettis	Jotunheimen, Norway	Utla River	1,215	370
Hunlen	British Columbia, Canada	Hunlen River	1,198	365
Tin Mine	Kosciusko National Park, Australia	Tin Mine Creek	1,182	360
Silver Strand	Yosemite National Park, California, U.S.	Silver Strand Creek	1,170	357
Basaseachic	Baranca del Cobre, Mexico	Piedra Volada Creek	1,120	311
Spray Stream	Lauterburnnental, Switzerland	Staubbach Brook	985	300
Fachoda	Tahiti, French Polynesia	Fautaua River	985	300
King Edward VIII	Guyana	Courantyne River	850	259
Wallaman	near Ingham, Australia	Wallaman Creek	844	257
Gersoppa	Western Ghats, India	Sharavati River	828	253
Kaieteur	Guyana	Rio Potaro	822	251
Montezuma	near Rosebery, Tasmania	Montezuma River	800	240
Wollomombi	near Armidale, Australia	Wollomombi River	722	2203

Source: Fifth Continent Australia Pty Limited.

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