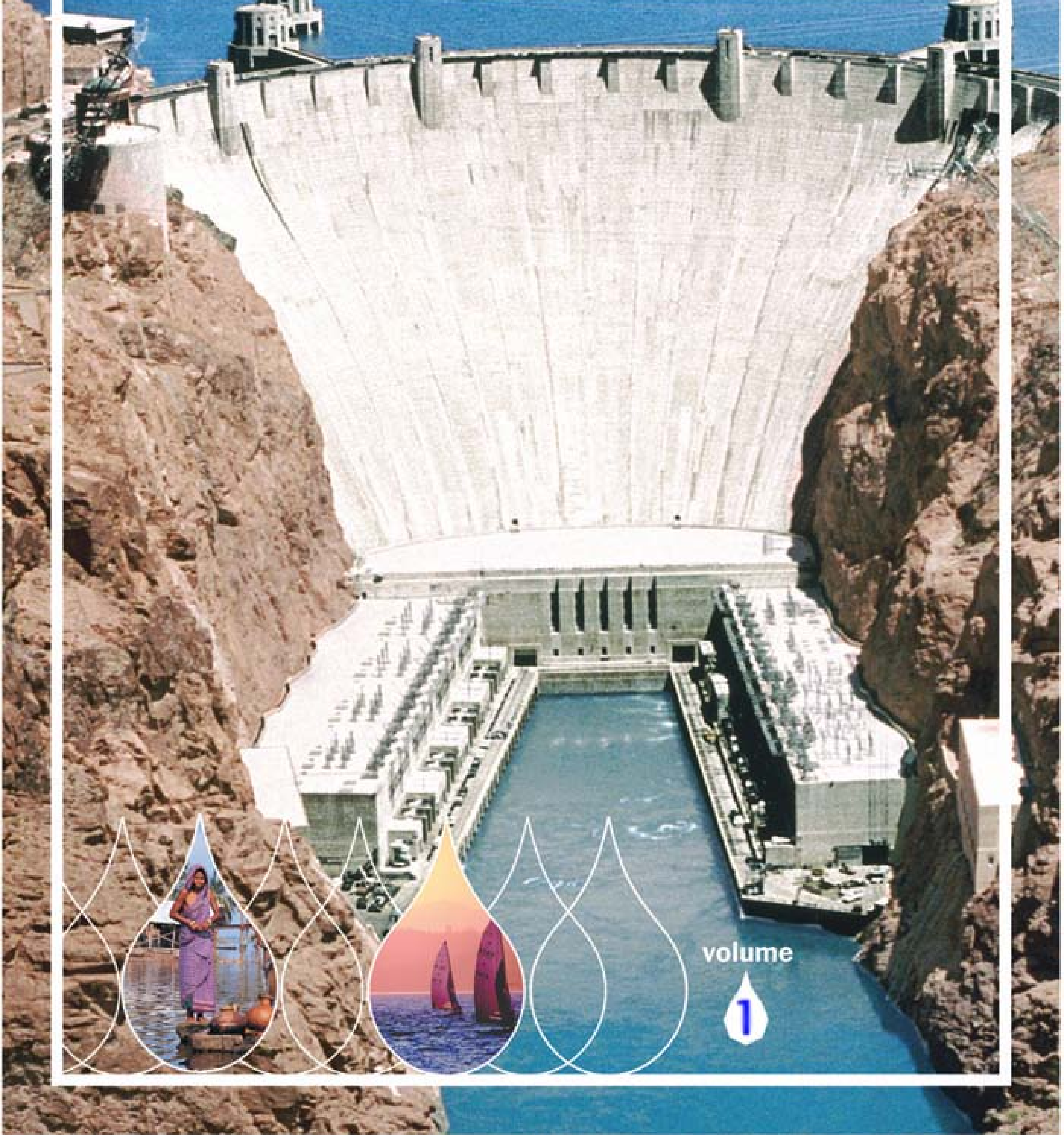
U•X•L ENCYCLOPEDIA OF water science



volume 1

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Volume 1
Science

K. Lee Lerner and Brenda Wilmoth Lerner, Editors

Lawrence W. Baker, Project Editor

U•X•L

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Reader's Guide

Water is important and special because it takes part in almost all of the processes that form and shape the Earth. Water is also essential to life. Without water, life—in all its many forms—would not be possible. The study of water science helps toward understanding how and why water plays such an important role.

Water also unites and divides us. Water is the subject of numerous treaties, laws, and agreements between nations, states, and communities. However, because water is an increasingly important and scarce resource, there are often complex legal and political issues surrounding the use of water. Many wars and court cases have arisen over who owns a body of water, who has a right to use it, or how water should be divided and used among those who claim it. To assure an adequate supply of water to meet broad needs of humans around the world, the development of scientifically sound strategies for sustainable water development are critical.

In many cases, disputes over water are related to preserving the quality of waters that nourish and protect both human and natural communities. To better understand these issues, one also needs to know the essentials of water science.

Scope and format

U•X•L Encyclopedia of Water Science takes an international perspective in exploring water science and water issues. The encyclopedia features more than one hundred entries in three volumes, with each volume broken into separate chapters:

Volume 1 (Science): Basics of water science; Oceans and saltwater; Fresh water; Estuaries and wetlands; Ice; Water, weather, and climates

Volume 2 (Economics and Uses): Science and technology; Science and research; Economic uses of water; Recreational uses of water; History and culture

Volume 3 (Issues): Environmental issues; Legal and political issues

Within each chapter, entries are arranged alphabetically. Among the topics covered in Volume 1 are the Hydrologic cycle; Kelp and seaweed; Lakes; Wetlands; Glaciers; and Clouds. Volume 2 covers Dams and reservoirs; Marine biology; Petroleum exploration and recovery; Tourism on the oceans; Dangerous waters; and Exploration of the oceans. And Volume 3 includes topics such as Acid rain; Groundwater issues; Oil spills; Sediment contamination; Endangered species laws; and Exclusive economic zones.

Each entry provides definitions for scientific terms and sources for further research. In addition, a general glossary, a research and activities section, and a cumulative index to the set are included in each volume. Numerous sidebars highlight significant facts and describe water-related activities. More than 150 black-and-white photos—as well as a different set of color photo inserts in each volume—help illustrate *U•X•L Encyclopedia of Water Science.*

Acknowledgments

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Dedication

The editors lovingly dedicate this book to the brave men and women of the U.S. Navy and the U.S. Coast Guard.

"The sea, washing the equator and the poles, offers its perilous aid, and the power and empire that follow it.... 'Beware of me,' it says, 'but if you can hold me, I am the key to all the lands.'" —Ralph Waldo Emerson (1803–1882), *The Conduct of Life,* "Wealth"

Comments and suggestions

We welcome your comments on *U•X•L Encyclopedia of Water Science.* Please write: Editors, *U•X•L Encyclopedia of Water Science,* U•X•L, 27500 Drake Rd., Farmington Hills, MI 48331; call toll-free: 1-800-877-4253; fax: 248-699-8097; or send e-mail via http://www.gale.com.

K. Lee Lerner and Brenda Wilmoth Lerner, editors

Words to Know

A

Abiotic: Nonliving part of the environment.

Abyssal plain: Vast, flat areas of the deep-ocean floor.

Abyssopelagic zone: The deep ocean that extends from 13,000 feet (4,000 meters) below the surface to the seafloor.

Acid deposition: The collective term for dry deposition and wet deposition of acids as a result of air pollution.

Acid rain: The result of acidic chemicals reacting in the atmosphere with water and returning to Earth as contaminated rain, fog, or snow.

Aeration: Adding oxygen, nitrogen, and other gasses necessary for respiration into water.

Agar: A mixture of sugars found in some types of seaweed that can form a solid surface used in laboratories to grow bacteria.

Air mass: Large body of air with only small variations of temperature, pressure, and moisture.

Air pressure: Force exerted by the weight of a column of air above a particular location.

Algae: Fresh and salt water plants that can convert the Sun's energy into food; they range in size from microscopic cells to forms that are bigger than a person.

Algal bloom: The rapid and huge increase in numbers of algae that can occur in the presence of a food source such as phosphorus.

Alpine glacier: Mass of moving ice that is confined by mountain valleys.

Ambergris: A highly prized fat found in the intestines of some whales.

Anadromous: Fish that are born in fresh water and then move to marine water as adults.

Annelid: A segmented worm such as an earthworm or a polychaete worm.

Antarctic ice cap: Ice covering the continent of Antarctic and Southern Ocean region around the South Pole.

Anticyclone: An atmospheric system associated with dry, clear weather with winds that spiral out away from a center of high atmospheric pressure.

Aquarist: Person who keeps an aquarium.

Aquatic: Relating to water.

Aqueduct: A channel or conduit, usually resembling a bridge, that carries water on land or over a valley, from a higher point to a lower one.

Aquiclude: Permeable (leaky) layers of rock or soil that confine and pressurize groundwater within aquifers.

Aquifer: An underground rock formation that contains water.

Archaeological context: The natural surroundings, physical location, and cultural origin of archaeological artifacts or sites.

Archimedes principle of buoyancy: An object submerged in a fluid is pushed upward by a buoyant force equal to the weight of the fluid it displaces.

Arctic: Region of the Earth between the North Pole and the Arctic circle.

Arctic Circle: Invisible circle around the North Pole above latitude at 66°33' North.

Arctic ice cap: Ice covering the Arctic Ocean and land areas north of the Arctic Circle in the North Pole.

Arid: Lack of rainfall. An arid climate has an annual rainfall of only 10 inches or less per year.

Artesian flow: Water that rises to the land surface from confined aquifers without pumping.

Arthropod: A member of a group of invertebrates that has jointed appendages and an external skeleton.

Artifact: Any object made or modified by humans.

Atmosphere: A unit to measure pressure; one atmosphere is 14.7 pounds per square inch, which is the standard atmospheric pressure measured at sea level.

Atmospheric (barometric) pressure: Pressure caused by the weight of the atmosphere over a surface or object.

Atoll: Ring-shaped coral island that surrounds a shallow lagoon.

Atom: The smallest unit that has all the chemical and physical characteristics of an element.

Autecology: Ecological study of individual organisms or individual species.

Autonomous underwater vehicle (AUV): Remote-controlled motorized crafts that are designed to study and withstand the pressure of the deep ocean.

Autotroph: Organism that uses inorganic substances to produce energy.

B

Bacterioplankton: Plankton composed of bacteria, often serving as the basis of the aquatic food chain.

Baleen: Bristly plates that hang from the upper jaws of baleen whales; acts like a sieve for the microscopic animals during feeding.

Ballast water: Water that is pumped into the hull of a ship to keep the ship balanced correctly in the water when it is empty.

Barge: Large, usually flat boat used for shipping.

Barometer: An instrument used to measure atmospheric pressure.

Barrage: Artificial obstruction such as a dam constructed in a water channel to increase water depth or divert flow.

Barrier Island: Long, narrow coastal island built up parallel to the mainland.

Basalt: Black iron- and magnesium-rich volcanic rock common in ocean basins.

Base level: The water level at the outlet of a stream, usually sea level; streams cannot erode below this level.

Bathymetry: The three-dimensional shape of the seafloor.

Bathypelagic zone: The layer of the ocean below the mesopelagic zone and above the abyssopelagic zone; generally it extends between 3,250 feet (1,000 meters) and 13,000 feet (4,000 meters) below the surface of the ocean.

Bathyscaphe: A submersible vehicle that is capable of going to the deepest parts of the ocean and withstanding extreme pressure.

Beach: Region of sand or rock that slopes down to the water of a lake or ocean.

Benthic: Animals, plants, and microorganisms that live on the floor of the ocean.

Bioaccumulation: Tendency for substances to increase in concentration in living organisms as they take in contaminated air, water, or food.

Biodiversity: The variety of living organisms and the ecosystems in which they occur.

Bioluminescence: Light that is generated by chemical reactions in bacteria, animals, and plants.

Bioremediation: The use of living organisms such as bacteria to remove pollutants from natural resources, such as water.

Biosphere: All the biological communities (ecosystems) that exist in the world.

Biotic: Living part of the environment.

Black smoker: Underwater seep of volcanic magma that deposits minerals.

Boreal forests: Treed areas of the northern temperate regions of North America, Europe, and Asia that are dominated by evergreen trees like firs, pines, and spruces.

Brackish: Water with a salinity (salt content) between that of freshwater and ocean water.

Braided stream: Streams with many channels that split apart and rejoin.

Brine: Water that contains a high concentration of salt.

Bulk carrier: A ship that carries large quantities of raw material, such as steel, timber, or grain, in large cargo holds.

Buoyancy: Ability of an object to float in a liquid.

Buoyant force: Upward force exerted by a liquid on an object; an object will float if the buoyant force of the liquid is greater than the downward force of gravity.

C

Caldera lake: Lake filling a large circular depression left by a volcanic eruption or collapse.

Canal: Man-made or artificially improved waterway used for travel, shipping, irrigation, or hydropower.

Canoe: Boat pointed at both ends and typically with an open top, or deck.

Carbonate: Rock or loose sediment composed of the mineral calcite or calcium carbonate.

Cargo: Goods that are being transported.

Cargo hold: A section of a ship that is divided from other sections for the transport of a single type of cargo.

Cartilage: Tough but flexible material, found between bones in humans and in the skeletons of sharks and rays.

Cetacean: A member of the group of marine mammals that includes whales, dolphins, and porpoises.

Channel: The water-filled path of the stream, river, or man-made waterway.

Chemical oceanology: Study of the molecules and atoms that are dissolved in the ocean.

Chemistry: The science of the composition, structure, and properties of matter.

Chemosynthesis: The use of chemicals, rather than sunlight, for the production of food.

Cistern: A man-made reservoir for storing water.

Clearcut: The total removal of trees and much of the vegetation from a section of forest.

Climate: Long-term meteorological conditions or average weather.

Climate effect: Temperature and moisture patterns that characterize a large region over tens, hundreds, or even thousands of years.

Climate zone: Areas of the world with a characteristic climate. Climate zones are described as arid, Mediterranean, mountain, polar, temperate, and tropical.

Cnidarian: A member of a group of invertebrates that includes corals, jellyfish, and sea anemones; these organisms have stinging cells to capture prey.

Coastal zone: The shallow part of the ocean extending from the high-tide mark on land to the edge of the continental shelf.

Coastline: The land that lies next to the sea.

Commercially extinct: When an animal becomes too rare to be worth hunting.

Community: All of the organisms that live in a certain locations.

Compound: Substance in which two or more elements are joined together.

Computer model: Description of a system, theory, or phenomenon entered into a computer that includes its known properties and conditions and can be used to predict future conditions and events within the system.

Condensation: The transformation (phase change) of a gas to a liquid.

Conservation: Protection, management, or restoration of natural resources such as soil, forests, wetlands, minerals, and water.

Container ship: A ship that transports cargo in sealed containers that may be unloaded directly onto trains or trucks.

Contaminant: Polluting substance that has harmful effects on biological life and other natural systems.

Contamination: Polluted or containing unwanted substances.

Continental glacier: Very large, dome-shaped mass of glacial ice that completely covers the terrain beneath it; also called ice sheet.

Continental shelf: The edge of a continent that gently slopes in relatively shallow water before dropping off steeply to the great depths of the open ocean.

Convection: Circulation of a gas or liquid driven by heat transfer and gravity.

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES): A 1973 treaty that restricts international commerce between participating nations for plant and animal species that are believed to be harmed by trade.

Coral: A rocklike deposit formed of the calcium carbonate skeletons of a group of small sea animals.

Coral reef: Tropical marine feature created by numerous colonies of tiny coral animals; coral reefs contain a great diversity of marine animals.

Coriolis effect: The effect of the Earth's rotation on the atmosphere and oceans that causes deflection to the right in the northern hemisphere, and deflection to the left in the southern hemisphere.

Crest: The highest point of a wave. Also, the highest level of floodwaters during a flood.

Cretaceous period: A division of geologic time from 65 to 144 million years ago; along with the Jurassic and Triassic, this period comprised the Mesozoic Era known as "the age of the dinosaurs."

Crevasse: A large crack or fissure in the surface of a glacier.

Cruise ship: A large ship, once used as the primary means of transporting people across an ocean, that now serves as a vacation destination, while visiting various ports of interest.

Crustacean: A member of a group of arthropods that includes brine shrimp, barnacles, copepods, shrimp, lobsters, crabs, and euphausids.

Curation: Cleaning, preserving, and storing artifacts recovered from archaeological sites for further study.

Current: The circulation of ocean waters that produces a steady flow of water in a prevailing direction.

Cyclic changes: Changes that repeat themselves over time.

Cyclone: Rotating atmospheric system of winds that flow into a low-pressure center. Cyclones rotate counterclockwise in the northern hemisphere and clockwise in the southern hemisphere.

D

Dam: A physical barrier constructed across a river or waterway to control the flow or raise the level of water.

Decibel: Unit that measures the loudness or intensity of sound.

Deep-sea fishing: Form of fishing that requires boating several miles out to sea in order to catch fish that live far from shore, such as marlin, tarpon, and barracuda.

Deforestation: Large-scale removal of trees from a woodland.

Delta: The sedimentary deposit that forms at the mouth of a river. Delta means "triangle" in Greek, and river deltas are usually triangular.

Density: The amount of mass-per-unit volume of a substance. In water, density is primarily determined by the combination of salinity and temperature.

Dentricles: V-shaped structures that make up the rough skin of a shark.

Deposition: Process by which dirt, silt, and sand is moved from its original place by wind or water and deposited elsewhere.

Depositional coastline: A coastline formed from the sediment of carbonates, plants, and animals that have hard mineral shells made of calcium carbonate.

Desalination: Process of removing salt from sea water or water contaminated with salt.

Desert: An area of land that receives less than 10 inches (25.4 centimeters) of precipitation per year.

Desertification: Gradual changes that take place over a region or area of land that ultimately result in the formation of a desert.

Detergent: A chemical used as a cleaning agent because it encourages the formation of an oil-in-water emulsion.

Diatoms: Single-celled phytoplankton that produce a thin shell made of silica (glass).

Dinoflagellates: Single-celled phytoplankton that move by propelling whip-like appendages called flagella.

Dipolar molecule: A molecule that has a positive charge at one end and an equal, but opposite, negative charge at the other end.

Discharge zone: Land area where groundwater flows out of aquifers on to land surface.

Dispersant: A chemical agent that reduces the surface tension of liquid hydrocarbons, encouraging the formation of an oil-in-water emulsion. This reduces the volume of residual oil on shorelines or the water surface after a spill.

Dissolution: When water breaks rocks into dissolved chemicals; a form of erosion.

Distillation: The purification of water by heating.

Distributary: Channel of water that runs through deltas.

Diversion: Changing the direction of a water body such as a stream or river by building canals, dams, or channels.

Divide: High point or ridge that separates drainage basins, and in which water flows down in all directions.

Diving suit: Sealed suit that receives a constant supply of air, usually surface air supplied by hoses; used for early ocean dives.

Doldrums: A zone of dead air and still water, usually at the equator where the trade winds and equatorial currents converge.

Downwelling: Ocean zones where surface water sinks into the deep ocean.

Dowsing: Pseudoscientific practice of using alleged spiritual powers and a "divining rod" to locate underground water.

Drag: A force that resists movement.

Drainage basin: Land area from which surface runoff drains into a stream or lake.

Dredge: Device for scooping or digging rock and sediment from the seafloor.

Dredging: A process where a ship drags a hook or grate along the bottom of a waterway in order to remove the accumulated silt and mud.

Drought: A temporary but extended period of abnormally low rainfall.

Dry deposition: Acidic gases and solid particles containing acids that settle out of the air and land on surfaces.

Dynamic equilibrium: State of balance attained by maintaining equal rates of input and withdrawal from a system.

E

Echinoderm: A member of the group of invertebrates that includes feather stars, sea stars, brittle stars, sea urchins, and sea cucumbers.

Echolocation: The ability of dolphins, bats, and some other animals to detect objects and prey by emitting sound waves that bounce off objects and return to the animal's ears or other sensory organ.

Echosounder: A tool that bounces sound waves off the ocean floor to record water depths or create maps of the ocean floor.

Ecology: Study of the relationships among organisms and between organisms and their environment.

Ecosystem: Community of plants and animals that interact with each other and with their physical environment.

Ecotourism: Tourism that focuses on nature and the environment without harming it.

Ectotherm: An animal that has a body temperature similar to that of its environment.

Effluent: Wastewater that has been treated to remove most impurities.

Electrical current: Flow of electricity.

Electromagnetic spectrum: The range of electrical waves of varying wavelengths that make up light. The visible range is only a small portion of the full spectrum.

Electron: A particle with a negative charge that orbits the nucleus of an atom.

Element: A substance that cannot be divided by ordinary chemical means.

Embayment: Indentation in the shoreline that forms a bay.

Endangered: A species that is in danger of becoming extinct within the foreseeable future throughout all or a significant portion of its natural habitat.

Endangered Species Act: Law passed in 1973 that identifies species that face possible extinction and implements measures to prevent extinction; species may be listed as either endangered or threatened under the act.

Endotherm: An animal that can maintain a relatively constant body temperature regardless of its environment.

Endothermic: Chemical reaction or phase change that absorbs energy.

Environmental impact study: A survey conducted to determine if a landfill project could have negative effects on the environment.

Environmental Protection Agency: Federal agency responsible for enforcing laws designed to protect the environment, including air quality, water quality, wetlands, hazardous wastes, and other environmental matters.

Epilimnion: The surface of a lake that extends as deep as light penetrates.

Epipelagic zone: The surface of the ocean where light penetrates; also called the photic zone.

Equatorial current: A sustained pattern of water flowing westward near the equator.

Erosion: Wearing away of soil, rock, sand, or other material by the action of wind and water.

Erosional coastline: A coastline formed by rising tectonic plates that gradually wears away.

Escherichia coli: Type of bacteria that is found in the intestines of warm-blooded animals including humans; some types can cause illness if ingested.

Estuary: Wide part of a river where it nears the sea; where fresh and salt water mix.

Eutrophic: Waters with a good supply of nutrients.

Eutrophication: Proliferation of plant life, especially algae, that results when excess nutrients are added to lake or pond water, which reduces the oxygen content and often causes the death of animals.

Evaporation: The change of liquid water to water vapor.

Exclusive economic zone: A 200-mile (322-kilometer) area extending from a nation's coastline that permits that nation to extract resources such as oil, gas, and fish and to pass laws to protect those resources.

Exothermic: Chemical reaction or phase change that produces heat.

Export: Raw materials or goods that are shipped, traded, or sold to other nations.

Extinction: The total disappearance of a species; the irreversible loss of a living species.

Eye: Small circular area of relative calm at the center of a cyclone.

F

Ferry: Ship that transports cars and people across bodies of water on a regular schedule.

Filtration: The process by which pollutants are removed from water.

Fishing regulations: Restrictions placed on where, when, and how fish may be caught.

Fixed wave power device: Wave power electrical generator that is attached to the seafloor and/or shore.

Fjord: A long, narrow, deep glacial valley flooded by the sea.

Flash flood: Flood that rises and dissipates rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area.

Floating wave power device: Wave power electrical generator that is floating in shallow water.

Floodplain: Flat land adjacent to rivers that are subject to flooding during periods of heavy rainfall.

Food chain: Relationship of organisms in an ecosystem in which each member species feeds on other species.

Food web: The predator and prey relationships between animals and plants.

Free diving: Underwater swimming without the use of a breathing apparatus; also known as skin diving or breath-hold diving.

Frond: A long, feathery leaf, or the blade of a kelp plant or sea plant.

Front: The boundary between two air masses of different temperature and humidity.

G

Generator: Machine that converts mechanical energy to electrical energy.

Geothermal: Heat from Earth; energy obtained from the hot areas under the surface of the Earth.

Glacial erratic: Boulders carried by glaciers and deposited away from their original location.

Glacial flour: Sediments that have been crushed and ground into a fine texture beneath a glacier.

Glacial outwash: Sand and gravel deposited by water melting from a glacier.

Glacial till: Sediments, or the rock, gravel, and sand carried and deposited by a glacier.

Glacier: Large mass of moving ice.

Global warming: Increase in the average temperature of the Earth's surface.

Gorge: A deep, narrow ravine, often with a river or stream running through it.

Graben: Rifts or holes formed when tectonic plates pull away from each other; when filled with water they can form large lakes.

Graded profile: A stream or river with a constant slope (incline).

Graded stream: A stream that has achieved a constant slope (profile) by reaching a balance of erosion and deposition.

Gravity: The natural force of attraction between any two objects that depends upon the mass of the objects and the distance between the objects. Planets, like Earth, draw objects toward their surfaces. Attraction is directly proportional to the product of the masses of the bodies and inversely proportional to the square of the distance between the bodies.

Gray water: Water that has been used for bathing, in the kitchen, or other purposes that do not generate highly-contaminated wastewater.

Greenhouse effect: The process where light from the Sun is reflected off Earth's surfaces and then trapped by clouds to warm Earth's atmosphere and surface.

Greenhouse gases: Gases in Earth atmosphere's that include water vapor and carbon dioxide, methane, nitrous oxides, ozone, halogens (bromine, chlorine, and fluorine), halocarbons, and other trace gases (gases found in very relatively small amounts).

Greenhouse layer: Layer of gases in the atmosphere that lets pass incoming solar rays and traps escaping heat.

Gross tons: A marine term equal to 100 cubic feet (about 10 cubic meters) used to describe the size of a boat, ship, or barge.

Groundwater: Freshwater that resides in rock and soil layers beneath Earth's land surface.

Groyne: A wall-like structure that sticks out into the water from the beach, which is intended to trap material.

Guyot: A flat-topped submarine mountain.

Gyres: Large circular patterns created by surface water currents in the oceans.

H

Habitat: The environment in which a species naturally or normally lives and grows.

Hadal zone: The layer of the ocean in deep trenches and submarine canyons at depths that can extend down to 35,750 feet (11,000 meters).

Halite: A mineral composed of sodium chloride, commonly known as rock salt.

Halocline: Layer of water where the salinity changes rapidly with depth.

Headland: Point that extends into the ocean; usually a high rocky point surrounded by sea cliffs.

Heavy metal: Element such as lead or mercury that tends to be toxic to plant and animal life, even when present in a low concentration.

Heterotroph: Organism that consumes another organism to obtain energy.

Himalaya Mountains: Tall mountain range in central Asia that includes nine of the world's ten highest peaks, including the tallest one, Mt. Everest.

Holdfast: The part of a seaweed that allows the plant to attach to a rock.

Holoplankton: Plankton that spend their entire life cycle floating and drifting among the currents.

Homeostasis: Tendency for a system to resist change.

Hovercraft: Ship that floats over the surface of the water on a cushion of air.

Humidity: Water vapor (moisture) in the air.

Hurricane: An organized storm (tropical cyclone) with sustained winds of 74 miles per hour (119 kilometers per hour) or greater in the Atlantic Ocean, Gulf of Mexico, Caribbean Sea, or eastern Pacific Ocean.

Hydrocarbon: Chemical substance made up of carbon and hydrogen; propane, gasoline, kerosene, diesel fuel, and lubricating oil are common hydrocarbons.

Hydrofoil: Ship that has wing-like foils under the hull of the ship that provide lift that raises the hull of the ship out of the water.

Hydrogeologist: Scientist who studies the properties and distribution of freshwater, especially as it relates to the soil and rock structure of the Earth.

Hydrologic potential: Potential energy in water stored in reservoirs above the elevation of a river downstream.

Hydrologist: Scientist who studies the properties and distribution of Earth's freshwater.

Hydrophilic: Easily dissolvable in water.

Hydrophobic: Not easily dissolvable in water.

Hydrosphere: The whole body of water that exists on or around Earth, including water in the atmosphere, lakes, oceans, rivers, and groundwater.

Hydrothermal deposit: Mineral-containing geologic unit that was formed by hot waters percolating through source rocks.

Hydrothermal vents: Volcanic-powered, hot spring openings in the ocean floor that spew out a fluid that is rich in chemicals and minerals.

Hypolimnion: The deep part of a lake where no light penetrates.

Hypopycnal flow: River water that floats on top of sea water as it flows out to the ocean; it is caused by the fact that river water is less dense than salty sea water.

Hypothermia: Condition in which the body becomes too cold to function properly.

Hypoxia: Condition in which the concentration of oxygen in body tissues is too low for the body to function normally.

I

Ice budget: The total amount of frozen water on Earth.

Ice cap: Ice at the poles; large dome-shaped glaciers that are smaller than ice sheets.

Ice front: The ice at the lowest end of a glacier.

Ice sheet: Very large, dome-shaped mass of glacial ice that covers a large continental area; also called continental glacier.

Ice shelf: A floating platform of ice where an ice sheet flows out over water.

Ice stream: Portion of a glacier or ice sheet that flows faster than the surrounding ice.

Iceberg: Large chunk of ice that breaks off from glaciers and floats in the oceans.

Ichthyology: The scientific study of fish.

Import: Raw materials or goods that are produced in a foreign country and brought into another.

In situ: In place.

Industrial Revolution: Period of rapid industrial growth, usually dated from 1750 to 1900, that resulted in a shift from economies based on agriculture and small businesses to economies based on industry and large corporations.

Influent streams and ponds: Bodies of surface water in recharge zones that contribute groundwater.

Interdistributary: Land or water that is between distributaries in deltas.

Internal combustion engine: An engine that takes the energy in fuel and combusts (burns) it inside the engine to produce motion.

International Maritime Organization (IMO): International agency of the United Nations that is concerned with shipping regulation and safety.

International organization: A group that includes two or more countries and that operates in more than one country.

Intertidal: The zone of the seashore between the high tide point and the low tide point.

Inuit: The native human inhabitants of the Arctic coastal regions of Eastern Asia (Siberia), North America and Greenland; also known as Eskimo, although this term has fallen out of favor.

Invertebrate: An animal without a backbone.

Ion: An electrically charged atom or group of atoms.

Irrigation: Diverting freshwater from lakes and rivers for use in agriculture to provide water for crops.

J

Jet stream: High-speed winds that race around the planet at about five miles above the Earth.

Jetty: Structure built out into the sea, a lake, or a river to protect the harbor or shore against waves or tides.

K

Karst: Landscape with caverns, sinkholes, underground streams, and springs created by erosion of limestone rock layers by groundwater.

Kayak: Boat that is pointed at both ends and has a closed deck except for a small hole where the paddler sits.

Kettle: Round depression left in glacial sediment after melting of a buried block of ice; it forms lakes and ponds when filled with water.

Kettle pond: Small round pond that forms when a melting glacier leaves chunks of ice buried in its deposits.

L

Lagoon: A shallow body of water that is separated from the sea by a reef or narrow island.

Lake overturn: Mixing of lake waters from temperatures causing changes in the water layers' density.

Land bridge: Strip of dry land that connects islands or continents when it is exposed by lowered sea level during glacial periods.

Latitude: Imaginary lines that tell how far north or south a place is from the equator.

Lava: Hot, liquid rock that reaches the Earth's surface through a volcano or opening in Earth's crust.

Leachate: An acidic wastewater that contains contaminants from decomposed materials in a landfill.

Lentic: Relating to waters that are moving, like in rivers and streams.

Levee: A natural or man-made wall along the banks of a stream channel that helps confine floodwaters within the channel.

Limnology: Study of the ecology of continental surface waters including lakes, rivers, wetlands, and estuaries.

Liner: A sheet of plastic or other material that is put on top of clay on the inside of a landfill to prevent material from leaking out of the landfill.

Lithosphere: Rocky outer shell of Earth that is broken into large, rigid pieces called plates.

Littoral zone: Shallow, sunlit zone along lake shores where rooted plants grow.

Lock: One in a series of gates that allows boats or ships to pass through multiple water levels.

Longshore current: Near-shore current that runs parallel to a coastline.

Lotic: Relating to waters that are stationary, like in ponds and lakes.

M

Macroplankton: Plankton large enough to be seen by the naked eye, including larval forms of jellyfish and some species of crustaceans.

Magnetometer: Used in marine archaeology to locate shipwrecks by finding metal objects used in the ship's construction such as nails, brackets, decorative ironwork, or artillery.

Malacostraca: A class of marine invertebrates that includes shrimp, lobsters, crabs, and euphausids.

Mammal: A vertebrate that nurses its young with milk, breathes air, has hair at some point in its life, and is warm-blooded.

Mariculture: Farming of marine animals and aquatic plants in a controlled marine environment.

Marine biology: Study of life in the ocean.

Marine geology: Study of the formation and structure of underwater land and rock formation.

Marine Mammal Protection Act: Law that seeks to increase the population of marine mammal species by prohibiting the hunting, capture, or killing of marine mammals.

Marsh: Wetland dominated by grasses, reeds, and sedges.

Meandering stream: A stream with a channel that follows a twisting path of curves and bends.

Mesopelagic zone: The layer of the ocean below the epipelagic zone and above the bathypelagic zone; generally it extends from about 500 feet (150 meters) to about 3,250 feet (1,000 meters).

Metabolic rate: The rate at which the biochemical processes occur in an organism.

Metal: Substance that is a conductor of electricity and heat.

Meteorology: The science of atmospheric conditions and phenomena.

Mid-ocean ridge: A continuous chain of low, symmetrical volcanoes that extends through all the ocean basins.

Milankovitch cycles: Predictable changes in Earth's average temperature that are caused by changes in Earth's position relative to the Sun.

Mines: Explosive devices that usually explode when an object makes contact with them; sea mines usually float on or just below the surface.

Molecule: A group of atoms arranged to interact in a particular way; the smallest part of a substance that has the qualities of that substance.

Mollusk: A member of a group of invertebrates that includes the snails, clams, oysters, scallops, mussels, squid, and octopuses.

Monsoon: A wind from the southwest that brings heavy rainfall to India and other parts of southern Asia during the summer.

Moraine: A ridge formed by the unsorted gravel, sand, and rock pushed by a glacier and deposited at the outer edge, or front, of the glacier.

Mousse: A water-in-oil emulsion that is formed by turbulence of the surface water after a petroleum spill to the aquatic environment.

Municipality: A village, town, or city with its own local government that provides services for its residents.

N

National Weather Service: Government agency that predicts the weather and warns the public of dangerous weather situations and their consequences, including severe weather and flood warnings.

Native species: A species naturally occurring in an environment.

Natural gas: Naturally occurring hydrocarbon gas.

Natural resources: Economically valuable materials that humans extract from the Earth; water is one of humans' most essential natural resource.

Navigable: Describes a body of water wide and deep enough for boats or ships to travel.

Navigation: The ability to determine the correct position of a ship in the ocean and the direction to sail in order to reach the desired destination.

Navigation channel: Passage in a waterway that is naturally deep or dredged to permit the passage of ships, or a defined, well-marked passage that leads from the docks to open waters; also called ship channel.

Navigation rights: The right of the ships from one nation to pass through certain waters, particularly the territorial waters of another nation.

Neap tide: Lowest tides of the month that occur at the second and fourth quarters of the Moon.

Neutron: A particle found in the nucleus of an atom that has no electric charge.

Non-point source pollution: Water pollution that comes from several unidentified sources, such as contaminated rain, runoff, or groundwater.

Nor'easter: A gale or storm blowing from the northeast, particularly common in New England and eastern Canada.

Nutrient: Chemical such as phosphate and nitrate needed by organisms in order to grow.

O

Ocean currents: The circulation of ocean waters that produce a steady flow of water in a prevailing direction.

Oligotrophic: Describing a body of water in which nutrients are in low supply.

Open-pit mine: Large craters dug into the earth to extract ore that is near the surface.

Ore: Naturally occurring source of minerals.

Organic: Of or relating to or derived from living organisms.

Overfishing: Catching a species of fish faster than it can naturally reproduce resulting in a decline in the overall population of that species.

Ozone layer: Region in the outer atmosphere that absorbs the Sun's harmful ultraviolet radiation.

P

Pangea: A super-continent that existed about two hundred million years ago when all of Earth's continental land masses were joined.

Parts per million (ppm): The number of particles in a solution per million particles of the solution.

Pathogen: Organisms (such as bacteria, protozoa, and viruses) that can cause disease.

Peat: Compressed organic material found in bogs.

Permafrost: Frozen layer of soil beneath the top layer of soil that has remained frozen for two or more years.

Permeability: The ability of fluid to move through a material.

Pesticides: Substances used to kill or harm unwanted plants, insects, or rodents.

Petroleum: A naturally occurring liquid mixture of hydrocarbons that is mined and refined for energy and the manufacturing of chemicals, especially plastics. Also known as crude oil.

Phase change: Transformation of a substance between one phase of matter (solid, liquid, or gas) to another.

Phosphorus: An element used as a food source by a variety of plants and microorganisms.

Photosynthesis: The process where plants use sunlight, water, and carbon dioxide to produce their food.

Physical oceanography: Study of the physical properties of the ocean including temperature, salinity and density, the ability to transmit light and sound, and the flow of currents and tides.

Phytoplankton: Plankton composed of plants and plant-like bacteria, such as algae.

Pinniped: A member of the group of marine mammals that include seals, sea lions, fur seals, and walruses.

Placer deposit: Water-deposited mineral source, such as gold nuggets in streams.

Plankton: Small, often microscopic, organisms that float in the ocean.

Plate tectonics: The theory that Earth's lithospheric plates move over time. It explains geological patterns of earthquakes, mountain chains, volcanoes, and rock types.

Platform: Large buildings, attached to the sea floor or floating, that house workers and machinery needed to drill for oil or gas.

Playa: Flat areas at the bottom of desert basins that occasionally fill with water.

Pleistocene Epoch: Division of geologic time from 10,000 to 2 million years ago; also known as the Ice Age.

Point-source pollution: Water pollution that enters the water body from a particular site.

Point-source wastewater: Wastewater that enters natural waters from defined locations.

Polar: A molecule that has a positively charged part and a negatively charged part.

Polychaeta: The largest class of segmented worms that live in the ocean.

Population: Group of organisms all belonging to the same species that live in a specific location.

Porosity: Amount of empty space within a rock or soil body.

Port: City or town on a harbor where ships dock and cargo is loaded or unloaded.

Potable: Water that is safe to drink.

Precipitation: Transfer of water as rain, snow, sleet, or hail from the atmosphere to the surface of Earth. In chemistry or geochemistry: The process in which ions dissolved in a solution bond to reform a solid.

Proton: A positively charged particle that is located in the nucleus of an atom.

Purification: Process by which pollutants, mud, salt, and other substances are removed from the wastewater.

R

Rainshadow: An area that has decreased precipitation because a barrier mountain range causes prevailing winds to lose their moisture before reaching it.

Recharge zone: Area where water enters groundwater reservoirs by infiltrating through soils, stream beds, and ponds.

Reclamation: Draining submerged or wetter land to form dry, usable land.

Reef: An underwater ridge of rock or coral near the surface of the ocean.

Remote sensing: The use of devices to collect and interpret data; in marine archaeology, remote sensing is used to locate, map, and study underwater sites.

Remotely operated vehicle (ROV): Motorized crafts designed to withstand the increased pressure of the deep ocean.

Reservoir: Natural or man-made lake or body of water, often constructed to control a body of water.

Reservoir rocks: Rocks where petroleum collects.

Residence time: Time an average water molecule spends in one of the reservoirs of the hydrologic cycle.

Respiration: Process in which an organism uses oxygen for its life processes.

Ring of fire: A zone of large volcanoes and earthquakes that surrounds the Pacific Ocean.

Riparian zone: Narrow strip of vegetation that is found bounding the edge of a natural water body such as a stream or river.

River system: A river and its network of headwater streams and tributaries. All the streams that contribute water to the main river.

Runoff: Excess water when the amount of precipitation (water falling to Earth's surface) is greater than the ability of the land to soak up the water.

S

Sailing: Moving across the water in a boat powered by wind energy harnessed by sails.

Saline lake: Saltwater lake that contains high concentrations of dissolved salts.

Salinity: A measure of the salt concentration of seawater.

Sanctuary: A habitat where killing animals or plants is prohibited.

Sanitation: Maintaining clean, hygienic conditions that help prevent disease through the use of clean water and wastewater disposal.

Saprotroph: Organism that decomposes another organism into inorganic substances and in the process obtains energy for itself.

Scuba diving: "Scuba" is the acronym for self-contained underwater breathing apparatus, referring to the air tanks and mouthpieces used by divers.

Sea ice: Frozen seawater floating on the ocean surface.

Seafloor spreading: The process by which a new oceanic seafloor is created by small volcanic eruptions at mid-ocean ridges.

Seamount: An underwater mountain.

Sedge: Grass-like plants.

Sediment: Particles of gravel, sand, and silt.

Seismic waves: Vibrations emitted by earthquakes and large explosions that travel as waves through the Earth.

Semipermeable: Descriptive of a material that allows the passage of some molecules and prevents the passage of others.

Sensor: Device that can detect the waves that have bounced back from the object they contacted.

Sewer system: Network of channels or pipes that carry wastewater to a treatment facility for purification.

Shoreline: A strip of land within a coastal zone that is submerged by high tide; also called shore zone.

Sidescan sonar: Type of sonar that emits sound energy over a wide path, tens or hundreds of miles (kilometers) across, allowing scientists to map large areas of the ocean.

Silt: Sedimentary particles smaller than sand particles, but larger than clay particles.

Sinkhole: A crater that forms when the roof of a cavern collapses; usually found in limestone rock.

Sludge: A semisolid residue, containing microorganisms and their products, from any water treatment process.

Snorkel: A hollow tube attached to a mouthpiece that can jut out above the surface of the ocean to allow a diver to breath.

Snorkeling: Form of diving in which the diver swims at or near the surface of the water using a snorkel to breathe surface air.

Snow line: The lowest elevation where snow stays on the ground or glacier surface without melting.

Solar salt production: A process that yields sea salt by allowing the sun to evaporate saltwater.

Solution: A liquid that contains dissolved substances.

Solution mining: Producing table salt by pumping water underground where it dissolves halite, then returning the solution to the surface where the salt is recovered through evaporation.

Solvent: A substance, most often a liquid, into which other compounds can dissolve.

Sonar: Derived from "SOund NAvigation and Ranging," sonar uses sound waves to locate underwater objects.

Source rocks: Mud layers rich with plant and animal material that become rocks where temperature and pressure transform the plant and animal material into petroleum.

Species: Group of organisms that have a unique set of characteristics, such as body shape and behavior, and are capable of reproducing with each other and producing offspring.

Sponge: One of the least complex multicellular animals; a member of the phylum Porifera.

Spring tide: Highest tides of the month that occur at the new and full Moon.

Stratified: Layered.

Stream: Moving surface fresh water driven towards sea level by gravity.

Stromata: Holes on the surface of leaves that can let water vapor pass out of the plant into the air.

Subarctic: Region just below the Arctic Circle, to the edge of the northern forests in North America, Europe, and Asia.

Subduction: Process by which oceanic seafloor is recycled into Earth's interior at deep ocean trenches.

Submersible: A craft designed to carry a pilot and scientists for underwater study of the deep ocean.

Superfund: A program managed by the Environmental Protection Agency that identifies, investigates, and cleans up the worst hazardous waste sites in the United States.

Surface mixed layer: The surface of the ocean where wind acts as a mixer, dissolving gases such as oxygen into the water.

Surface water: Water that is located on the surface, naturally in the form of streams, rivers, lakes, and other waterways, or in reservoirs, swimming pools, and other containers that have been built.

Sustainability: The use of a natural resource in a manner where it can be maintained and renewed for future generations.

Swamp: Wetland dominated by trees.

Swash: The forward and backward motion of water where waves break upon the shore.

Synecology: Ecological study of groups of organisms and how they work together.

T

Tanker: A ship that transports liquid cargo, usually oil or chemicals.

Tectonic plate: Moving plates of Earth's crust.

Temperate zone: Region characterized by moderate temperatures, rainfall, and weather and overall climate that is neither hot nor cold, wet nor dry.

Tentacles: Long appendages on sea organisms that contain suckers or stinging cells and are used to grasp food and move around.

Terra cotta: Ceramic materials made from baked clay used in Ancient Rome for aqueduct pipes, dishes, and some tools.

Territorial water: Ocean waters governed by a nation; most territorial waters extend for 12 miles (19.3 kilometers) from a nation's coastline.

Thermal spring: Natural spring of water at a temperature of 70°F (21°C) or above; commonly called a hot spring.

Thermocline: The part of the ocean below the epipelagic zone where the temperature changes very quickly with depth.

Threatened: Descriptive of a species that is likely to become endangered in the foreseeable future.

Tidal fence: Device installed in an area with highly-changing tides that makes electricity by harnessing tidal energy.

Tidal flat: A broad, flat area of coastline alternately covered and exposed by the tides.

Tidal wave: The swell or crest of surface ocean water created by the tides. Also refers to an unusual water rise along a coastline as created by a storm or undersea earthquake.

Tide: Periodic rise and fall of sea level along coastlines caused by gravitational and rotational forces between the Sun, Moon, and Earth.

Tornado: A violently rotating column of air that is in contact with the ground.

Trade winds: Strong winds that blow from east to west in the subtropics on either side of the equator; named for their part in propelling European sailing ships to the East and West Indies to conduct trade.

Transpiration: The process where water is absorbed by a plant through its roots and passes into the air from the leaves as water vapor.

Treaty: An international agreement between two or more nations in written form and governed by international law.

Tributary: Smaller streams that flow into a larger stream or river.

Tropical storm: A low pressure storm system formed in tropical latitudes with sustained winds between 39 and 74 miles per hour (63 and 119 kilometers per hour).

Tropics: Warm, humid region lying north and south of the equator.

Trough: The lowest point in a wave; occurs between the crests.

Tsunami: Very large ocean wave created by an undersea earthquake or volcanic eruption.

Tundra: Treeless plains of the arctic and subarctic between the northern forests and the coastline of the Arctic Ocean.

Turbine: Device that converts the flow of a fluid (air, steam, water, or hot gases) into mechanical motion for generating electricity.

Twister: Common name for a tornado.

Typhoon: Tropical cyclone in the western Pacific or Indian oceans.

U

United Nations: An association of countries founded in 1945 that is devoted to the promotion of peace, security, and cooperation between nations.

United Nations Law of the Sea: International law that governs the rights and responsibilities of nations and their approach to the oceans.

Upwelling: An area where cold, often nutrient-rich water rises from the deep ocean to the surface.

U.S. Department of the Interior: Department in the U.S. government that is responsible for the conservation of natural resources and the administration of government-owned land.

U.S. Geological Survey: Division of the U.S. Department of the Interior that is responsible for the scientific analysis of natural resources, the environment, and natural disasters.

V

Vertebrate: An animal that has a bony spine that contains a nerve (spinal) chord.

W

Wall cloud: An area of clouds that extends beneath a severe thunderstorm and sometimes produces a tornado.

Wastewater: Water left over after it has been used, such as any water that empties into a drain or sewer.

Water allotment: An individual portion of water granted by a water right.

Water chemistry: The balance of nutrients, chemicals, and minerals in water.

Water footprint: The amount of water used by an individual, business, community, or nation.

Water right: Grants a right to use water but not ownership of the waterway.

Water table: The zone above which the spaces in the soil and rocks are not completely filled with water and below which the soil and rock spaces are completely filled with water.

Water treatment: A series of steps that makes water potable and removes chemicals and microoganisms that could be harmful to the natural environment.

Watershed: The land area that drains water into a river or other body of water.

Waterspout: A column of rotating air, similar to a tornado, over a body of water.

Wave base: Water depth at which water is undisturbed by a passing wave. Wave base is at a depth equal to half the horizontal distance between two neighboring wave crests (one-half wavelength).

Wave refraction: Wave fronts bending when they approach a coastline at an angle.

Wavelength: Distance of one full wave; can be measured from crest to crest or trough to trough.

Weir: A low dam built across a stream or any flowing body of water, usually with rocks, to raise its level or divert its flow.

Wet deposition: Precipitation that has become acidic as a result of air pollution.

Wetlands: Areas of land where water covers the surface for at least part of the year and controls the development of soil.

Z

Zone of infiltration: Shallow soil and rock layers with pore space that are at least partially filled with air; water table is the bottom of this zone.

Zone of saturation: Soil and rock layers with pore spaces that are completely filled with fluid; water table is the top of this zone.

Zooplankton: Small, often microscopic, animals that float in the ocean.

Research and Activity Ideas

The following research and activity ideas are intended to offer suggestions for complementing science and social studies curricula, to trigger additional ideas for enhancing learning, and to provide cross-disciplinary projects for library and classroom use.

• **Experimentation:** The following resources contain simple experiments that illustrate the physical properties of water:

Project WET (Water Education for Teachers), an international nonprofit water education program and publisher located at Montana State University. http://www.projectwet.org/index.html.

Janice VanCleave's Oceans for Every Kid: Easy Activities That Make Learning Science Fun, by Janice Van Cleave, Wiley, 1996.

Exploring the Oceans: Science Activities for Kids, by Shawn Berlute-Shea and Anthony B. Fredericks, Fulcrum, 1998.

Oceans Alive: Water, Wind, and Waves, by Doug Sylvester, Rainbow Horizons, 2001.

Why Is the Ocean Salty? by Herbert Swenson, U.S. Government Printing Office, Superintendent of Documents. Prepared by the U.S. Geological Survey to provide information about the earth sciences, natural resources, and the environment.

• **Adopt a creature:** Take a class vote to choose a freshwater or marine creature to adopt whose species is stressed or endangered. Research the life of the creature, prepare a class display, and learn about the latest efforts to conserve the species and its habitat. Suggestions for creatures to adopt include the:

Manatee: Information about adopting a manatee can be found at the Save the Manatee Club Web site, http://www.savethemanatee.org/default.html.

Humpback whale: Information about adopting a humpback whale can be found at the Whale Center of New England Web site, http://www.whalecenter.org/adopt.htm.

Sea turtle: Information about adopting a sea turtle that has been fitted with a transmitter for tracking can be found at the Seaturtle.org Web site, http://www.seaturtle.org/tracking/adopt/.

Whooping crane: Information about adopting a whooping crane can be found at the Friends of the Patuxent Wildlife Center Web site, http://www.friendspwrc.org/.

Salmon: Information about participating in the Adopt-a-salmon program can be found on the U.S. Department of Fish and Wildlife Web site, http://www.fws.gov/r5cneafp/guide.htm.

• **Newspaper search:** Locate and review newspapers for the following disasters using the dates given. Assess if reporters grasped the cause and extent of the event. Choose interesting accounts to read to the class. The events are: hurricane in Galveston, Texas, on September 8, 1900; drought in the southern plains of the United States, 1930–39 (also called the Dust Bowl); tsunami in the Gulf of Alaska on March 28, 1964; Arno River floods in Florence, Italy, on November 4–5, 1966; and *Amoco Cadiz* oil spill off the coast of Brittany, France, on March 16, 1978. Old issues of local newspapers are likely available at your public library, a nearby college or university library, or from the local newspaper office itself.

• **At the movies:** Watch one of the following popular movies, each of which contains content about Earth's water sources or its ecosystems. *20,000 Leagues Under the Sea* (1954), *Jaws* (1977), *Into the Deep* (1991), *A River Runs Through It* (1992), *Free Willy* (1993), *The Living Sea* (1995), and *Finding Nemo* (2003). Applying your knowledge of water science, how was the issue portrayed in the movie? Whether the movie was a drama, comedy, or documentary, was the science portrayed accurately? Were there misconceptions about water science issues that it relayed to the audience?

• **Debate #1:** Divide the class into two groups, one in favor of the United States ratifying the United Nations Law of the Sea and the other against. Students should defend their positions about the environmental, economic, and political benefits or hardships that adopting the law would bring the United States, and whether U.S. ratification would change the state of the world's oceans.

• **Debate #2:** Divide the class into two groups, one in favor of large dam projects on major rivers and the other against. Students should research China's Three Gorges project, the Sardar Sarovar Project in India, and the Hoover and Glen Canyon dams. Debate the issue, with students defending their positions on hydroelectric power, water supply, flood control, and recreation enabled by dams, along with the environmental impacts, displaced persons, and detriments of flooding an area for a reservoir that occur when large dams are constructed.

• **Interviews:** Make a list of persons who have visited or lived near beaches, lakes, rivers, or wetlands for a long period of time. Parents or grandparents would be good candidates. Interview them about the changes in the area that they have noticed over time, such as changes in the water quality or quantity, new or reduced populations of water creatures, habitat change, and encroaching development. Develop questions ahead of time. Tape record the interview if possible or take careful notes. Transcribe the recording or notes into a clear written retelling of the interview. This process is known as taking and recording an oral history. Share the oral history with the class.

• **Aquarium:** Plan a class trip to a local aquarium. Notice the environment required for particular species such as water salinity, depth, temperature, presence of other unique features (coral reef, rocks, caves, plants) and available food sources. Design a model aquarium of several compatible species, labeling the particular features needed by each species. If a home aquarium sounds like an interesting hobby, the following Web sites provide helpful information for getting started: "Aquariums as a Hobby" from SeaWorld's *Animals: Explore, Discover, Connect* Web site at: http://www.seaworld.org/infobooks/Aquarium/Aquarium.html and "Starting a New Aquarium" from the *World of Fish* Web site at: http://meltingpot.fortunecity.com/oltorf/729/id18.htm.

• **Conserve water:** Make a checklist of ways to conserve water in the home. Include: using low-flush toilets (or placing a closed container of water in non-low-flush toilet tanks), checking faucets for leaks, using aerators on faucets, collecting rainwater for watering gardens, watering landscapes during early morning hours, landscaping with native plants that demand less water, installing low-flow shower heads, and using other water-saving measures found while researching the topic of water conservation. Inspect your home according to the checklist to learn ways that your family can help conserve water and discuss this with family members. Make checklists to distribute to other students at your school.

• **Stay informed:** Three current challenges facing the world's oceans are often featured in the news media. Watch and listen for reports about diminishing coral reefs in the Caribbean Sea and in the Pacific Ocean, about warming ocean temperatures, and for reports about noise pollution interfering with marine mammal communication. Get the details of one of these current issues with research. Web sites of oceanographic institutes and universities are good places to begin collecting information.

• **"Water Science for Schools"** The U.S. Geological Survey maintains the Web site "Water Science for Schools," which provides teachers and students with information and activities for learning about water science and water resources. The Web site is located at: http://ga.water.usgs.gov/edu/ and includes excellent information about the water cycle, Earth's water resources, and how humans use water. The site includes pictures, data, maps, and an interactive center.

• **Map project:** Research the watershed areas of local rivers, lakes, and streams. Using colored chalk or highlighters, color-code and shade the watershed areas on a large street map. Post the map in the community to raise awareness of the watershed, along with measures people can take to protect it from contamination.

Chapter 1
Basics of Water Science

Biochemistry (Water and Life)

Water is found in all forms of life on Earth in some form or another. The human body is about 70% water, and other organisms, such as jellyfish, contain as much as 95% water. All of the oxygen that animals breathe had its origin as water. During photosynthesis (the process of using light to create food energy), plants break water apart to produce oxygen and food.

Water is one of the most abundant molecules on Earth. There are approximately 350 million cubic miles (1.4 billion cubic kilometers) of water on the planet. Nearly 97% of all water is found in the oceans, which cover two-thirds of the surface area of the planet. About 90% of all fresh water is frozen in the ice in the North and South Poles and glaciers (large slow-moving masses of ice). Less than 1% of all the water on Earth is available for consumption, and most of it is found in aquifers (porous rock chambers holding fresh water) underground.

Characteristics of water

Water is a simple, yet extremely important, molecule comprised of one oxygen atom and two hydrogen atoms (an atom is the smallest part of an element that has all the properties of the element, and a molecule is two or more atoms held together by chemical bonds). The water molecule's small size and biochemical properties allow it to bond easily with other molecules. In fact, water is involved in almost every biological reaction.

Water has many chemical and physical properties that make it useful to cells and organisms. Water acts as a solvent (a liquid in which other substances are dissolved). Water sticks to

Stanley Miller working in a laboratory in which he created conditions similar to Earth 3.5 billion years ago and created elementary organic molecules essential for life. © *Bettmann/Corbis. Reproduced by permission.*

WORDS TO KNOW

Atom: The smallest unit that has all the chemical and physical characteristics of an element.

Density: The amount of matter contained within a given volume.

Electron: A particle with a negative charge that orbits the nucleus of an atom.

Hydrophilic: Easily dissolvable in water.

Hydrophobic: Not easily dissolvable in water.

Ion: Molecule made up of a positively charged atom and a negatively charged atom.

Neutron: A particle found in the nucleus of an atom that has no electric charge.

Photosynthesis: The process where plants use sunlight, water, and carbon dioxide to produce their food.

Polar: A molecule that has a positively charged part and a negatively charged part.

Proton: A positively charged particle that is located in the nucleus of an atom.

Wavelength: Specifies the energy and frequency of light.

itself and to other things, which allows it to flow slowly and to fill small places. Water is the only material that can exist naturally as a solid, liquid, and gas at Earth's natural temperatures. It takes a lot of energy to change the temperature of water, so water maintains stable temperatures well. Water also transmits light, allowing photosynthesis to occur underwater.

Water is polar

Water is composed of one oxygen atom and two hydrogen atoms. The oxygen atom has eight positively charged particles, called protons, and eight negatively charged particles, called electrons. The protons move about in the nucleus (center of the atom). The electrons spin around the nucleus in what are called electron shells or orbitals. Different orbitals hold different numbers of electrons. The first orbital contains two of these electrons and the second orbital contains six. Hydrogen atoms contain one proton and one electron. When water forms, electrons are shared between each of the hydrogen atoms and the oxygen atom. The sharing of an electron between two atoms forms a covalent bond (this is not a physical bond, atoms do not touch). The covalent bonds result in full outer orbitals for both atoms: eight in the second orbital of the oxygen and two in the first orbital of the hydrogen.

Positive and negative electrical charges attract each other, like two positive charges repel each other. Because oxygen has

Water on Mars

The *Sojourner* rover performs experiments on Mars. Courtesy of NASA/JPL/Caltech. *Reproduced by permission.*

Water is so important to life on Earth that few scientists assume that life on any other planet is possible without water. In 1984, scientists from the National Aeronautics and Space Administration (NASA) and Stanford University found a meteorite (rock or metal that has fallen to Earth's surface from outer space) from Mars in Antarctica. After analyzing the meteorite, they said that the meteorite came from rocks that formed on Mars about 3.5 billion years ago. At that time, the atmosphere on Mars was similar to Earth's atmosphere today. It contained much carbon dioxide that helped keep the planet warm. Most scientists assume that at that time the planet was warm enough for water to form as a liquid and that an ocean existed on Mars. When scientists cut the meteor open, they found microscopic structures in the rock that look a lot like fossilized bacteria (microscopic single-celled organisms) from Earth. The only difference is that the structures in the Martian rock are about 100 times smaller than bacteria on Earth. This suggested, but did not prove, that bacteria did live on Mars many, many years ago.

Over time, the rocks on Mars absorbed the carbon dioxide from the atmosphere and the planet cooled down. The water from the Martian ocean probably either froze or became bound to rocks. Some scientists say that the water may still be available deep underground. In 2004, NASA sent two spacecrafts, *Spirit* and *Opportunity,* to Mars to look for signs of water. Both of these spacecrafts have confirmed that the landscape of Mars once contained water. Two major questions remain: How long ago did the water dry up? Is there any left underground? In the coming years, the development of spacecraft that can return rocks to Earth or that can date the rocks directly on the Martian surface will help answer those questions.

more protons than hydrogen, it has a greater positive charge. That causes the spinning electrons in the water molecule to be attracted to the oxygen. This results in extra negative charge in the oxygen part of the molecule, and a positive charge on the hydrogen part.

The oxygen molecule takes on a "V"-shape, with the oxygen part of the molecule at the bottom of the "V" and the hydrogens at the arms. The bottom of the "V" has a small negative charge, while the arms of the "V" have a small positive charge. This type of molecule is referred to as a polar molecule, because it has a positive pole (the bottom of the "V") and negative poles (the arms of the "V").

The polarity of water molecules allows them to interact with each other electrostatically (due to their charges). The positive pole of one water molecule will be attracted to one of the negative poles of another water molecule. This sort of attraction is called a hydrogen bond. Hydrogen bonds are weak bonds; they easily form and are broken. Each water molecule has the potential to form four hydrogen bonds with other molecules.

Water dissolves polar substances

Some molecules are made up of ions. Ions are atoms that have either lost or gained electrons. If the atom has lost electrons, it is positively charged. If the atom has gained elections, it is negatively charged. Ionic bonds form between positively and negatively charged atoms. In these molecules, no electrons are shared; instead, the atoms are held together by their opposite charges.

When ions are mixed with water, the positively charged atom is attracted to the negative poles of water molecules and the negatively charged atom is attracted to the positive poles of water molecules. Eventually, the attraction between the different parts of the ion and the water molecules will pull the ion apart, breaking the ionic bond and dissolving the ion into positively charged atoms and negatively charged atoms. The fact that water is effective at dissolving ions makes it a good solvent.

Molecules that are polar are able to dissolve easily in water. These substances are often called hydrophilic (or water-loving). Examples of hydrophilic molecules are table salt and table sugar (glucose). Some molecules, however, do not dissolve well in water. These molecules are not polar and they are termed hydrophobic (water-hating). Examples of hydrophobic molecules are fats and proteins.

The membranes (layers) that surround cells are made up of large fats and proteins that cannot be dissolved in water. However, because water is a small molecule, it can pass through these membranes. As a result, water can transport small nutrients that cells need through cell membranes without destroying any cell membranes and without requiring an input of energy. Similarly, water can transport small waste molecules out of cells.

Water sticks together

The hydrogen bonds formed between water molecules allow water to stick to itself. This is important for many biological purposes. For example, the surface tension (a force that controls the shape of a liquid) of water allows some animals, such as water striders (spidery-like water insects), to walk on its surface. When rain falls onto Earth, the viscosity (resistance to flow) of water slows the rate it flows over the surface, allowing more water to absorb into the soil where it can be used by plants.

Water changes temperature slowly

Oceans and lakes change temperature very slowly due to the amount of energy needed to alter the water's temperature. Thus, as water covers so much of Earth (nearly three-fourths of the planet), the planet has relatively stable temperatures. This means that animals and plants that live in water experience a relatively stable environment. Many animals and plants contain a lot of water in their bodies, which helps them minimize body temperature changes as well.

The energy required to change water from a liquid to a gas is extremely great because many hydrogen bonds must be broken. When a molecule of water gains enough energy to escape all the hydrogen bonds that surround it, it becomes water vapor. As this molecule leaves the liquid water, it takes with it all of its energy. This means the water left behind has less energy. This process is known as evaporative cooling. Many animals (like humans) use evaporative cooling to reduce heat in their bodies. Plants also use evaporative cooling to stay cool in strong sunlight.

Water is found in three states

At the temperatures and pressures found on Earth, water can be found as a gas, liquid, and solid. A notable property of water is that it is densest, and therefore heaviest, at about 39°F (4°C). Water turns to ice at even colder temperatures, 32°F (0°C).

When water turns to ice, it gains a crystal-like structure. In this form, nearly all the water molecules are joined by the maximum number of hydrogen bonds, which is four. [These hydrogen bonds force the water molecules to move away from each other compared to when they are in the liquid state. As a result, water expands when it is frozen. As it expands, it becomes less dense and, therefore, floats on liquid water. As a result, ice is lighter than cold water and so it floats on top of it. If it were not for this unique structure, ice could form in deep water through-

Camels

Camels are well known for the humps on their backs and for being able to go for long periods of time without water. Although it is tempting to think that the humps are large water storage tanks on the camels' backs, they are actually large mounds of fat. In some camels, the humps can weigh as much as 80 pounds (35 kilograms). The fat acts as a food supply for the camel, who can exist for up to two weeks in the desert without eating.

Camels have developed several physical adaptations to manage without much water in hot, dry climates. Camels' bodies normally use about 5 gallons (20 liters) of water a day. However, if water is scarce, camels lose up to 40% of their body weight in water and recover without any damage. Most animals can only lose about 20% of their body weight in fluid each day without threat of dehydration (excessive harmful water loss).

The bodies of camels can undergo large fluctuations in body temperature. Whereas humans maintain their body temperature within a narrow range of about 2°F (1°C), camels can withstand body temperatures that fluctuate about 10°F (4°C). Only at temperatures above 105°F (40°C) does a camel begin to sweat to cool itself, which helps to conserve water. In addition, with the hump as a fat storage tank, camels avoid having fat all over their bodies. Since fat is insulating and holds heat in, this allows camels to lose heat from all the other regions of their body, thereby enabling the camel to remain cooler than other animals would at similar temperatures.

Camels have developed a circulatory system that can handle large water losses. As humans become dehydrated, they lose water from their blood, which lowers blood volume and blood pressure, leading to fainting. Camels, instead, maintain the water in their blood and lose water from their fat tissues. This keeps their blood pressure relatively stable. In addition, the red blood cells of camels, which carry oxygen to the tissue cells of the body, are well adapted for managing large fluctuations in water. When camels are able to replace lost water, their red blood cells can swell to 240% of their usual size. In most other animals, red blood cells can only increase their size by 50%.

Camels have also developed specialized digestive and excretory systems that protect them from large fluctuations in water. When water is scarce, camels produce feces that are so dry they can be burned. The urine produced by camels can be a thick syrupy consistency, with twice as much salt as ocean water. When camels do need to drink large amounts of water to replace losses, their stomachs and intestines are specially designed to manage the large input of water.

out lakes and oceans, making it very difficult for animals to exist there in cold climates.

Water both transmits and absorbs light

Water has the property of transmitting some types of light, while absorbing or scattering others. The ways that different types of light interact with water benefits life on Earth. Ultraviolet light, which has very small wavelengths, can damage cells. However, water vapor in the atmosphere (mass of air surrounding Earth) absorbs light in the ultraviolet wavelengths, greatly decreasing the amount of ultraviolet light that reaches the Earth's surface. Blue and green wavelengths of light can pass through water relatively easily. These are wavelengths that are most effectively used by plants for photosynthesis. As a result, plants can grow and flourish in underwater environments such as lakes and oceans. Water strongly absorbs red wavelengths of light, which produce a lot of heat. Because water vapor is found throughout the atmosphere, much of the red light that hits the Earth is absorbed by water. This aids in keeping the temperature of the Earth warm enough for life to exist.

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WORDS TO KNOW

Atom: The smallest unit that has all the chemical and physical characteristics of an element.

Chemistry: The science of the composition, structure, and properties of matter.

Dipolar molecule: A molecules that has a positive charge at one end and an equal, but opposite, negative charge at the other end.

Element: A substance that cannot be divided by ordinary chemical means.

Groundwater: Underground water that fills pores in soil or openings in rocks; supplies the water for wells and springs.

Hydrosphere: The whole body of water that exists on or around Earth, including water in the atmosphere, lakes, oceans, rivers, and groundwater.

Ion: An electrically charged atom or group of atoms.

Molecule: A group of atoms arranged to interact in a particular way; the smallest part of a substance that has the qualities of that substance.

Precipitation: The process in which ions dissolved in a solution bond to reform a solid.

Solution: A liquid that contains dissolved substances.

Chemistry of Water

Water is the most common substance on Earth, covering almost three quarters of the planet's surface. Known by its chemical symbol, H_2O, water is the only known substance on Earth that naturally exists as a gas, liquid, and solid. The vast majority of water, about 97%, is in the oceans. The liquid form of water also exists in lakes, rivers, streams, and groundwater (water beneath Earth's surface that is held between soil particles and rock, often supplying wells and springs). In its solid form, water makes up sheets of ice on the North and South Poles, and permanent snow. Water also exists as water vapor (gas) in the atmosphere. The hydrosphere is the whole body of water that exists on or around Earth, which includes all the bodies of water, ice, and water vapor in the atmosphere. All life needs water to survive and the cells of all living things contain water.

Chemistry is the science of the composition, structure, and properties of all substances, called matter, that have mass and occupy physical space. On Earth, the unique chemistry of water determines, in large part, not only the chemistry of the hydrosphere, but also the chemistry of the solid Earth (geochemistry), the atmosphere (atmospheric chemistry), and the living Earth (biochemistry).

The water molecule

Water is made up of the elements hydrogen and oxygen. An element is a substance that cannot be divided by ordinary chemical means. Hydrogen, oxygen, nitrogen, silicon and iron are all common elements on Earth. Atoms are the building blocks of elements and all matter. An atom is the smallest particle that has the characteristics of an element. Water is composed of groups of atoms called molecules. A group of atoms arranged in a particular way makes up a molecule, which is the smallest unit of a substance that has the properties of that substance. Atoms and small molecules like water are so small that they cannot be seen with even the most powerful microscopes. Much of what is known about water molecules has been inferred from indirect observations and chemical experiments.

A water molecule is a group of three atoms arranged in a shape similar to Mickey Mouse's head; Mickey's face is a larger oxygen atom (symbolized by the letter O) and his ears are two smaller hydrogen atoms (symbolized by H_2). Strong chemical bonds, called covalent bonds, hold the hydrogen and oxygen atoms together. To form covalent bonds, atoms share subatomic particles (particles smaller than atoms) called electrons,

The chemistry of water determines the properties of water, from how it forms water drops to the role it plays in living things. *© John Gillmoure/Corbis. Reproduced by permission.*

which have a negative charge. Atoms also have subatomic particles that have a positive charge, called protons.

In a water molecule, H_2O, more of the shared electrons collect around the oxygen atom than around the hydrogen atoms. This gives the oxygen end of the molecule a negative electrical charge and the hydrogen ends a positive electrical charge. This property of the water molecule, called dipolarity, gives water many of its chemical and physical characteristics.

Chemical properties of water

In chemistry, positive and negative electrical charges attract each other, like charges (two positive charges) repel each other. The negative ends of dipolar water molecules are attracted to molecules and atoms with positive charges, and vice versa. The molecules within a raindrop, storm cloud, and ice cube are arranged with positive and negative poles (opposite sides of the atom) attached to one another. The positive charge near the hydrogen atoms and the negative charge near the oxygen results in the formation of a hydrogen bond.

The many hydrogen bonds between the liquid water molecules cause these molecules to stick together. Water molecules at the surface form even stronger hydrogen bonds with their neighboring molecules, causing the formation of a surface film (layer). This phenomenon is called surface tension. Water's high surface tension makes it more difficult for solid objects to

Why Is the Ocean Salty?

Have you ever heard a waiter ask, "Would you care for a nice glass of seawater?" Of course not! Seawater contains a very high concentration of dissolved chemicals called salts. While water is essential for human life, consuming too much salt can cause humans to become ill, and seawater is not drinkable.

In fact, almost all water on Earth, lake water, river water, ground water, even ice and rainwater, contains some dissolved chemicals. When rainwater falls on rocks, soils, and plants, more chemicals, including salts, dissolve into the water. The groundwater that flows from wells and springs contains the dissolved components (parts) of rocks like limestone. Rivers carry water and these dissolved materials to the oceans.

When seawater evaporates and forms clouds in the atmosphere, the salts stay behind. So, not only are Earth's oceans and seas salty, they are becoming saltier. Over time, some shallow, landlocked seas (entirely or almost entirely surrounded by land) actually dry completely and leave thick beds of salt behind. Shallow, landlocked seas in arid (extremely dry) regions like the Great Salt Lake in Utah and the Dead Sea in Israel are presently evaporating. The water in the Dead Sea is the saltiest on Earth. To make it drinkable, humans can remove the salt (desalinate) by boiling it, removing the salt crystals and capturing the steam.

penetrate the water surface than for submerged objects to move through water. Certain water bugs can walk on the film due to water's surface tension. Water forms bubbles and drops because surface tension pulls the shape of unconfined liquids into a ball. (Without deformation by forces like gravity, all raindrops and bubbles would be perfectly sphere-shaped.) A person washes cleaner in a hot bath than a cold one because hot water has lower surface tension than cold, making it better able to get into openings. Soaps and detergents also lower surface tension.

Surface tension is also partly responsible for capillary action (water's ability to rise in a small narrow tube called a capillary). Water molecules stick, or adhere, to the sides of the capillary, and surface tension forms a curved bridge, called a meniscus, across the opening. Adhesion at the capillary walls creates an upward force and cohesion holds the water surface together. The whole meniscus moves up or through the capillary. Water moves up through plant roots to leaves by capillary action. Capillaries carry blood through the human body. (Human blood is about 83% water.) Surface tension and other properties of the water molecule allow nutrients to enter and wastes to leave plant and animal cells. Surface tension aids in the exchange of oxygen and carbon dioxide in the human lungs. Groundwater moves through soil and rock openings by capillary action.

Water, the universal solvent

Water is called the universal solvent because many solid substances dissolve easily into water. Water molecules form hydrogen bonds with electrically charged atoms called ions and dipolar molecules other than water molecules. Table salt, for example, is composed of a positive ion, sodium (Na^+), and a negative ion, chlorine (Cl^-). In a salt molecule, the sodium and chlorine ions bond to one another. When table salt is dropped in water, the positive ends of the water molecules surround the chlorine and the negative ends surround the sodi-

A man carries baskets of seawater for traditional salt making on the beach near the village of Kusamba in Bali, Indonesia. © *Albrecht G. Schaefer/Corbis. Reproduced by permission.*

um. The salt molecule disappears, but its ions are still in the water. A liquid that contains dissolved ions is called a solution. When conditions in the solution change in some instances, the dissolved ions bond to one another and turn back into a solid, a process called precipitation. When the water in salt water evaporates, salt molecules reform.

Water on Earth is an ever-changing solution that dissolves and precipitates substances as it flows. Pure water has no smell, taste, or color. Most water on Earth, however, contains many dissolved materials. Seawater, for example, is a complex solution that contains traces of almost every naturally occurring element. Falling rainwater contains dissolved carbon dioxide. "Hard" water (water that contains minerals) that forms scale (crusty deposits) on the hot water heater and makes it hard to lather up for a shower contains dissolved magnesium and calcium. Water that stains a porcelain sink red contains dissolved iron. Water that smells like rotten eggs contains sulfur. Many cities and neighborhood water districts add fluoride to the tap water because it prevents tooth decay. Some dissolved materials such as lead, mercury, arsenic, petroleum, and pesticides (chemicals used to kill insects, rodents, and other pests) are hazardous to human and animal health, and can be absorbed by food crops that are irrigated with contaminated water. The United States has set drinking water standards to prevent harmful chemicals from entering the drinking water supply.

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Hydrologic Cycle

Water is in constant motion. Energy from the sun and the force of gravity drive the hydrologic cycle, which is the endless circulation of water between the land, oceans, and atmosphere (air surrounding Earth). Water also changes in form: from gas (water vapor), to liquid, to solid (ice). Rain and snow falling on the land runs off into streams and lakes, or soaks into soil and rocks. Streams and rivers carry water downhill to lakes and, ultimately, to the ocean. Heat energy from the Sun transforms liquid water at the surface of lakes and oceans and other bodies of water into water vapor. Water vapor in the atmosphere rises and forms clouds. Cooling within clouds causes water vapor to become liquid once again. Rain and snow fall and the cycle begins anew.

The water budget

Earth's water budget, the total amount of water on the planet, does not change over time. The hydrologic cycle is a closed system. Water is constantly moving and changing form, but it is neither created nor destroyed. With the exception of a very small amount of water added to the hydrologic system by volcanic eruptions and meteors from space, Earth's total water supply is constant. In fact, most of the water on Earth today has been recycling through the hydrologic system for billions of years. The same water that comes from a kitchen faucet today could have been drunk by a dinosaur 170 million years ago during the Jurassic Period. It could have been frozen in an ice sheet during the Pleistocene Epoch (a division of geologic time that lasted from 2 million to 10,000 years ago), and could have flowed through a canal in the Roman Empire two thousand years ago. It could have been snow in the Rocky Mountains last winter, flowed in a river to the city's municipal water intake, and out of the faucet this morning. Maybe it will return to the river via the sink drain and city sewage system, and then flow to the ocean.

Reservoirs

Within the hydrologic system, water resides in environments called reservoirs. Earth's largest reservoirs, the oceans, contain about 97% of the planet's total water. Ice, including sheets of ice on the North and South Poles and mountain glaciers (a large body of slow moving ice), and groundwater reservoirs called aquifers hold most of the remaining 3%. Reservoirs of readily useable fresh water— rivers, lakes, soil moisture, atmospheric water vapor, and water in living cells— account for only about 1% of the fresh water, and less than 0.02% of water on Earth.

If a bathtub filled with 100 gallons (379 liters) of water represented Earth's total water budget, three gallon (11 liter) jugs would hold all the fresh water, and the fresh water available for immediate use by humans would only fill a tablespoon. A microscope would be needed to see the droplet representing the water bound up in plants and animals.

Water processes

All of Earth's water molecules are in constant motion. (A molecule is the smallest particle of a substance that has the chemical characteristics of the substance. A water molecule, symbolized by H_2O, is made up of two hydrogen atoms and an oxygen atom.) Processes move water from one reservoir to another and within reservoirs. Liquid water flows downhill and circulates within lakes and oceans. Clouds of water vapor, liquid droplets, and ice crystals (snow) move across the sky. Even molecules bound in glacial ice flow downhill.

Energy from the Sun and the downward pull of gravity ultimately drive all the processes within the hydrologic cycle. Water cycle processes include evaporation, condensation, convection, precipitation, freezing and melting, groundwater flow, and runoff.

- *Evaporation* is the conversion of water from a liquid to a gas. Water moves from bodies of water and land to the atmosphere when heat from the Sun transforms liquid water to water vapor. Most (about 80%) of the water vapor in the atmosphere evaporates from the oceans, especially the tropical oceans near the equator. Transpiration is evap-

WORDS TO KNOW

Aquifer: An underground layer of rock or soil that yields useable water for human consumption.

Condensation: Transformation of a gas to a liquid.

Convection: Circulation of a gas or liquid driven by heat transfer and gravity.

Delta: The sedimentary deposit that forms at the mouth of a river. Delta means "triangle" in Greek, and river deltas are usually triangular.

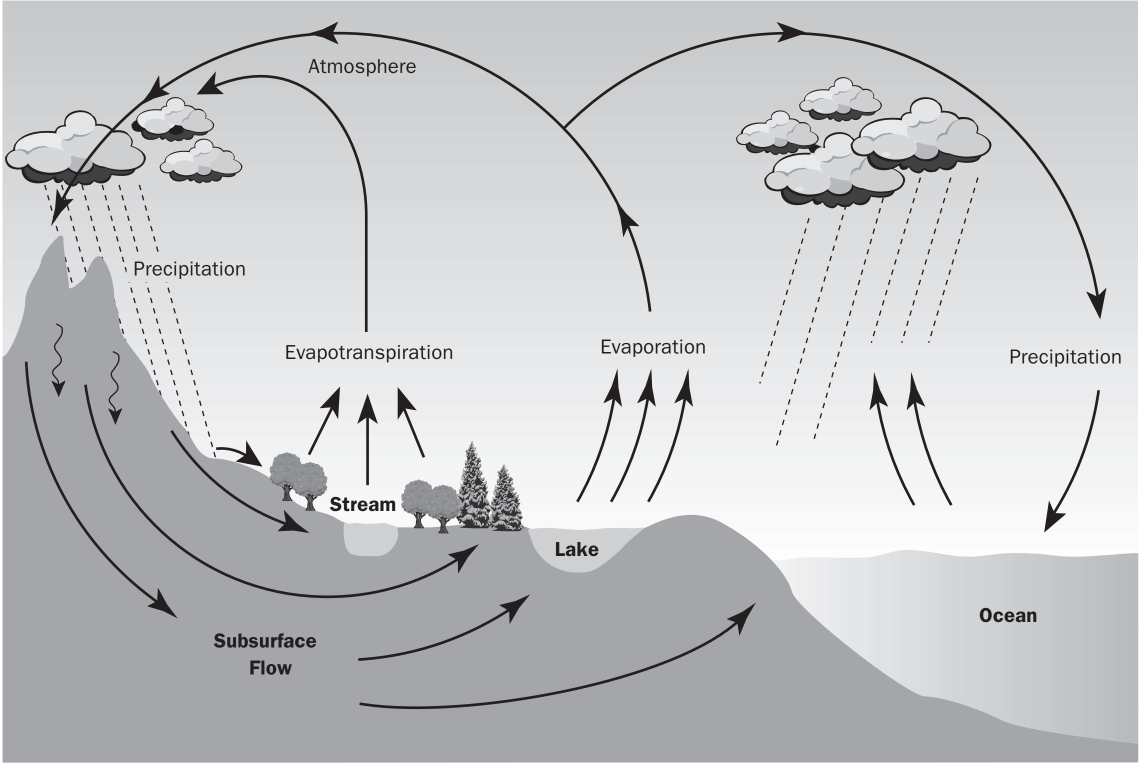
Dynamic equilibrium: State of balance attained by maintaining equal rates of input and withdrawal from a system.

Floodplain: Flat land adjacent to rivers that are subject to flooding during periods of heavy rainfall within the river system.

Precipitation: Transfer of water as rain, slow, sleet, or hail from the atmosphere to the surface of Earth.

Residence time: The period of time that water remains in a reservoir.

Transpiration: Evaporation of water from the leaves and stems of plants.



Water that falls to Earth as precipitation (mainly rain and snow) follows many paths before returning to the atmosphere. The hydrologic cycle describes how water cycles throughout the atmosphere, seas, and other reservoirs of water. *Thomson Gale.*

oration of water from the leaves and stems of plants. It contributes about 10% of the water vapor in the atmosphere, and evaporation from inland seas, lakes and rivers accounts for the remaining ten percent.

- *Condensation* is the conversion of water from a gas to a liquid. As air containing molecules of water rises in the atmosphere, the air cools, and the motion of the water molecules slows. The slower-moving water molecules accumulate as water vapor in the rising air. Water vapor then forms droplets of liquid water that group together into clouds, and eventually can fall as rain.
- *Convection* is the large-scale circulation of the atmosphere and oceans. Warm air or water rises and cool air or water sinks, creating currents (a steady flow in a dominant direction) that transport water around the globe. Convection causes winds that blow rain clouds over the continents, and ocean currents that transport heat, and affect global climate.
- *Precipitation* is the transfer of water from the atmosphere to Earth's surface. Rain, snow, sleet, and hail are all types of

precipitation. When condensed water droplets or ice crystals in a cloud become too large and heavy to remain aloft, they fall to the ground as precipitation. Amounts of precipitation vary greatly between locations. For example, the deserts of the American Southwest receive less than 1 inch (2.5 centimeters) of rain per year, while the summit of Mt. Waialeale on the Hawaiian island of Kauai receives more than 400 inches (1,016 centimeters) of rain per year. Heavy precipitation over a short amount of time can cause rivers and groundwater reservoirs to overflow and lead to flooding. Lack of normal levels of precipitation for an extended period of time causes the dried soil and reduced water supplies associated with drought.

- *Freezing and melting* are the transformations between liquid and solid water. Most freezing occurs in the atmosphere where condensed water vapor forms ice crystals in clouds. Glaciers form in areas near the North and South Poles and in high mountains where more snow falls than melts each year and ice accumulates over many years. In many regions, melting snow and ice replenish river and groundwater flow, as in aquifers, every spring. During the cold winter months in some regions, the surfaces of lakes and rivers freeze. In polar regions, even the seawater and groundwater freeze.
- *Groundwater flow* is the movement of liquid water through the pores (openings) in soils and cavities in rocks near Earth's surface. Surface water becomes groundwater by soaking into these tiny spaces, which were filled with air. Groundwater then percolates downward to the surface of the water table, the line where all the spaces are saturated (completely full) with water. Water below the water table flows toward areas of lower pressure where it can be released, such as springs or wells.
- *Runoff* is the transfer of water from the land surface to the oceans via streams and lakes. (Lakes only hold runoff temporarily, and lake water eventually ends up in the ocean.) Runoff consists of precipitation that neither evaporates back into the atmosphere, nor infiltrates into groundwater. Groundwater discharge can also replenish runoff. Excess runoff leads to flooding.

Dynamic equilibrium and residence times

All water molecules are in motion, but the total volume of water in a particular reservoir stays relatively constant because of a phenomenon called dynamic equilibrium. The processes that remove water molecules from a reservoir are balanced by the processes that add water. To illustrate, imagine trying to maintain a constant volume of water in a bathtub with an open drain. When the faucet is adjusted to add water at the same rate as it is draining, the water level stays constant, and dynamic equilibrium is reached. In the same way, sea level stays constant because the amount of water evaporating into the atmosphere matches the amount of water entering from rivers and melting glaciers. Over geologic time (the time from the formation of Earth to the present), this balance changes and the sea level rises and falls.

The atmosphere transfers water from the ocean to the land, but it only holds a tiny portion (.001%) of Earth's total water. Water has a short residence time in the atmosphere. Almost as soon (usually a few hours) as it evaporates into the air, water vapor condenses and falls again as precipitation. Water molecules stay in some glaciers, oceans, and groundwater reservoirs for thousands of years, while others only spend a few days or weeks in a reservoir. To maintain dynamic equilibrium, water must leave the reservoir at the same rate that it enters. In reservoirs with very long residence times, a change in the rate of water that enters or leaves can quickly affect the reservoir volume. For example, the Ogallala groundwater reservoir in the U.S. Great Plains region is a sandstone (rock formed from the compaction of sand) layer that filled with water a thousand years ago when the climate was wetter. In modern times, ranchers in Texas, Oklahoma, Kansas, Nebraska, and other states are using up the stored groundwater by withdrawing it much more quickly than it replenishes in today's dryer climate.

The hydrologic cycle as a component of the Earth system

The hydrologic cycle is intertwined with the other cycles that make up the Earth system. Moving water chemically and physically erodes (wears away) the solid Earth. It transports sediments (fine soil and other particles) and deposits them in river floodplains (lands near rivers that disperse overflow), deltas (where a river enters a lake or ocean, and continental margins (edges of continents that are underwater). It sculpts the land surface and seafloor. Water carries dissolved minerals and nutrients that nourish freshwater and marine ecosystems. Water in the oceans and atmosphere regulates Earth's climate and weather, which makes the planet habitable for biological life. Water is the largest component of most biological organisms. Jellyfish are more than 90% water. If a person weighs 120 pounds (54 kilograms), about 72 pounds (33 kilograms) of his or her weight is water.

Water is Earth's most essential renewable resource. It is conserved within the Earth system and cannot be "used up." However, water is very scarce in some regions and overly abundant in others. Deserts, rainforests, canyons, droughts, and floods all result from the uneven distribution of water on Earth. Scientists have concluded that human activities such as damming rivers, polluting waters, transporting water to arid (dry) regions to grow crops, and contributing to global climate change can alter the hydrologic cycle and change the patterns of water distribution. Water is continuously recycled and is ultimately a renewable resource, but challenges remain to manage water resources as the human population grows.

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Physics of Water

Why is water wet? Many people will answer this question by simply saying, "Because it is." The physical properties of water are fundamental to life and nature on Earth, and are often accepted as simple truths. Water is so common on Earth that its physical characteristics have a large impact on the physics of Earth in general. (Physics is the study of matter and energy, and of interactions between the two.) Water covers almost three quarters of the planet's surface. It is the only natural chemical substance that exists as a liquid, solid (ice), and gas (water vapor) within Earth's normal temperature range. Water is liquid in a range critical for biological life (0–100°C, 32–212°F), and liquid water is present almost everywhere on Earth. Water's ability to absorb heat regulates Earth's climate and weather.

Phase changes

Matter exists in three states, or phases: solid, liquid, and gas. (Matter is anything that has mass and takes up space). Substances like water change from one phase to another at specific temperatures and pressures. Add heat (or pressure), and a substance begins to change from a solid to a liquid at its melting point. Add more heat, and the substance will begin to evaporate, to turn from liquid to gas, at its boiling point. Remove heat (or pressure), and a substance will condense from gas to liquid and then freeze from liquid to solid. In water's solid phase, its molecules are bound together in a rigid framework called a crystal. (A molecule is a collection of two or more atoms held together by chemical bonds and an atom is the smallest unit of an element.) A water molecule, known by its chemical symbol H_2O, is a group of two hydrogen atoms and one oxygen atom. In liquid water, the molecules are still attached, but less strongly so, and they can move more freely. The molecules in water vapor are completely detached from one another and mingle with other types of atoms and molecules in air.

Phase changes either use or release heat energy. Melting and boiling are endothermic phase changes; they absorb heat. The opposite processes, freezing and condensing, release heat and are called exothermic phase changes. A block of ice, sitting in the sun, warms to the melting point of water (0°C or 32°F at sea level on Earth) and then begins to melt. The ice stays at exactly 32°F until it has completely melted. In this endothermic process, the heat is breaking the bonds between molecules within the ice crystal. Once the ice has melted, the resulting liquid water begins to absorb heat and the water temperature rises. When water temperature reaches the boiling point, 212°F (100°C), the chemical bonds between molecules break, and the water evaporates into its gas phase. Again, the liquid water stays at exactly 212°F (100°C) until the phase change is complete. During exothermic reactions, the temperature likewise remains the same until enough heat has been released for the phase change—melting for example—to become complete.

Pressure changes can also cause phase changes. Moun-taineers in the Himalayas can have trouble cooking their food because water boils at a lower temperature at high altitude (air pressure decreases at high altitude). For this reason, they sometimes carry pressure cookers that raise the temperature in the pot by trapping

WORDS TO KNOW

Archimedes' principle of buoyancy: An object submerged in a fluid is pushed upward by a buoyant force equal to the weight of the fluid it displaces.

Electromagnetic spectrum: The range of electrical waves of varying wavelengths that make up light. The visible range is only a small portion of the full spectrum.

Endothermic: Chemical reaction or phase change that absorbs energy.

Exothermic: Chemical reaction or phase change that releases energy

Phase change: Transformation of a substance between one phase of matter (solid, liquid, or gas) to another.

Sonar: Derived from "SOund NAvigation and Ranging," sonar uses sound waves to locate underwater objects.

Specific heat The amount of heat per unit required to raise the temperature of a substance by 1°C. Water has a high specific heat, and can absorb much energy before its temperature is raised.

Buoyancy: Archimedes and the King's Crown

The buoyant force supports the weight of this buoy covered with resting seals. © *Tim Thompson/Corbis. Reproduced by permission.*

Archimedes, a mathematician who was born in 287 B.C., first explained the principles of liquid displacement and buoyancy. Legend tells that the king of Syracuse on the island of Sicily asked Archimedes to find out if his beautiful crown was made of solid gold. The king suspected that the crown's maker had stolen some of the gold by substituting silver inside the crown. Archimedes considered the king's problem while bathing. He knew that silver is less dense than gold, so a part-silver crown would weigh less than a gold crown the same size. As he pondered ways to measure the volume (amount of space occupied) of the irregularly shaped crown, he noticed that the water level in the pool rose when he got into the bath, and fell when he got out of the bath. He put the crown in a basin filled with a measured amount of water. By calculating the amount of water displaced by the crown, he correctly estimated its volume. (To this day, pastry chefs use Archimedes' displacement method to measure butter or shortening.) Then he placed the crown on a scale and measured it against a pile of gold blocks of the same volume. Sadly for the deceitful craftsman, the scales tipped to the gold blocks instead of balancing the crown.

Archimedes' principle of buoyancy states that a completely submerged object displaces a volume of fluid equal to its own volume. The upward force placed on the object, called the buoyant force, is equal to the weight of the displaced fluid. If the object weighs more (has a greater mass) than the fluid it displaces, it sinks. If it weighs less, the buoyant force pushes it upward and it floats. Drop a steel ball in a pool, and it sinks because its density is greater than the density of water. A wooden ball the same size will float. A steel-hulled ship floats because it is hollow and the air contributes to the total mass. Add cargo, and the ship floats lower in the water. Add too much cargo, and it sinks. A submarine submerges by filling its tanks with water, and surfaces by filling the tanks with air. Archimedes' principle of buoyancy also correctly predicts that the tip of an iceberg is about one-eighth of a floating ice block. Ice is less dense than water, so icebergs float. However, they float with the majority of their volume below the water line.

steam and raising the pressure. Cake mixes have special high-altitude cooking instructions printed on the box. Ice-skaters can slide across the ice because the pressure of their skate blades temporarily melts the ice and forms a slippery film of liquid water.

Icebergs off the coast of Antarctica. Icebergs are nature's largest example of floating ice. *Commander Richard Brehn, NOAA Corps. National Oceanic and Atmospheric Administration. Reproduced by permission.*

Liquid water

Molecules in liquid water stick together. It takes a lot of heat energy to break the electrical attractions, called hydrogen bonds, between water molecules. Because of this, water has a high specific heat; it can absorb a lot of heat energy before it changes temperature. In general, heating raises the temperature in a liquid by making its molecules move faster in relationship to one another. In water, some of the heat energy is used to break the hydrogen bonds between molecules. When water cools, hydrogen bonds reform, and heat is released. Because of its high specific heat, liquid water can store a lot of energy, a property that has significant consequences for Earth's climate and biological life.

The oceans, Earth's massive reservoirs of liquid water, store and distribute heat energy from the sun. They absorb intense sunlight during the daytime and summer, and then release it slowly during the night and wintertime in the form of ocean currents. These currents carry stored heat from the tropics near the equator (an imaginary line around the Earth between the North and South Poles) toward the North and South Poles. Coastal and wet climates are usually milder than inland or arid (dry) climates. Water temperature stays relatively constant in the oceans, creating a stable environment for marine (ocean) ecosystems (communities of living organisms). Water protects organisms from temperature changes. Humans, who are composed mainly of water, can survive extreme hot and cold partly because water's high specific heat maintains human body temperatures at around 98.6°F (37°C).

Solid water: ice

Ice floats. Most liquids contract (draw together) as they cool and reach their maximum density (mass per unit of volume) as a solid. Water is different. It contracts until it reaches about 39°F (4°C), and then it expands until its molecules have all frozen into water's crystalline form at 32°F (0°C). So, cold water sinks, but ice floats. Water is the only natural substance on Earth that is less dense as a solid than as a liquid. If not for this property of water, bodies of water would freeze from the bottom up, ice cubes would sink in a water glass, and there would be no such thing as an iceberg (chunks of floating ice).

Gaseous water: water vapor

Water's phase transformation from liquid to gas occurs when molecules in liquid water escape and rise to mingle with other types of molecules and atoms in the atmosphere (mass of air surrounding Earth). Boiling occurs when the temperature within a volume of liquid reaches the point at which all the molecules are vibrating too rapidly to stay bonded to each other. Bubbles of gas escape, and eventually the liquid is gone. Water molecules also enter the gaseous phase by evaporation from the water surface. Water molecules in liquid water are constantly moving. Even at low temperatures, a percentage of the less-confined surface molecules move enough to break their bonds to their neighbors and escape into the atmosphere. Water from Earth's oceans, lakes, and rivers enters the atmosphere by evaporation and, fortunately for life on Earth, not by boiling.

It takes a lot of heat to break the hydrogen bonds in liquid water and to form water vapor. And, water vapor molecules' attraction to one another causes them to condense easily into liquid water droplets. Water prefers to be liquid. Water evaporating from the surfaces of Earth's oceans and other water reservoirs transfers heat into the atmosphere. When water vapor condenses into liquid droplets in clouds, heat is released and the air stays warm. Water vapor is an important greenhouse gas in Earth's atmosphere. A greenhouse traps heat in the atmosphere. Natural greenhouse gases in the atmosphere keep Earth warm, but not too warm. Water vapor's phase changes from liquid to gas and back to liquid act to trap incoming solar energy.

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Chapter 2
Oceans and Saltwater

Biology of the Oceans

All organisms that live in the ocean are subject to the physical factors of the underwater environment. Some of the more important factors that affect marine (ocean) organisms are light levels, nutrients (chemicals required for growth), temperature, salinity (concentration of salt in the water), and pressure. In general, conditions in the ocean are more stable than those on land.

Light

The amount of light in a certain location controls the growth of the single-celled marine algae called phytoplankton. Phytoplankton are the base of the marine food chain, meaning they are the food for other organisms, who then are the food for higher organisms and so forth. These plants convert sunlight and water into the carbohydrates (sugars) they feed on in a process called photosynthesis. Unlike land, where plants generally live on surfaces, in the ocean, light travels through the water allowing phytoplankton to grow over a vertical distance of nearly 500 feet in some locations (about 150 meters).

Light intensity decreases with depth in the ocean and some wavelengths (a property of light that determines whether the light is blue, red, ultraviolet, etc.) of light disappear more quickly than others. Blue light extends the deepest into the ocean, while red light is only present near the surface. Many factors influence how quickly light disappears. Near the coast, there may be high amounts of sediments (particles of sand, gravel, and silt) in the water and light may only extend 50 feet (15 meters). In the open ocean, the water is particularly clear and light may extend down 500 feet (150 meters).

WORDS TO KNOW

Ectotherm: An animal that has a body temperature similar to that of its environment.

Endotherm: An animal that can maintain a relatively constant body temperature regardless of its environment.

Eutrophic: Waters with a good supply of nutrients.

Hydrothermal vents: Natural springs that vent warm or hot water into the seafloor.

Metabolic rate: The rate at which the biochemical processes occur in an organism.

Nutrient: Chemical such as phosphate and nitrate needed by organisms in order to grow.

Oligotrophic: Describing a body of water in which nutrients are in low supply.

Osmosis: The tendency for water to have the same concentration on both sides of a semipermeable barrier.

Phytoplankton: Microscopic plants, such as algae, floating in seawater that form the basis of the food web.

Salinity: Amount of salt found in one kilogram of water.

Semipermeable: Descriptive of a material that allows the passage of some molecules and prevents the passage of others.

Because the phytoplankton must live where there is light, their predators live there as well. Many fish, crustaceans (aquatic animals with no backbone and a hard shell), and mollusks (soft-bodied animals without a backbone enclosed in a shell) are found in surface waters where phytoplankton grow. Many of these species use light to hunt prey and avoid predators. Light is also important in the life cycles of many fish and invertebrates (animals without a backbone) who use the changing length of the day as a calendar to trigger breeding periods.

Nutrients

Just as people need nutrients to grow, phytoplankton in the ocean also need nutrients. Nutrients are substances that are required for an organism to grow. Phytoplankton absorb nutrients that are dissolved in the water around them. Some nutrients are abundant in ocean water: carbon, oxygen, and sulfur. Others are relatively scarce and become even scarcer when phytoplankton are growing rapidly. The two most important of these are nitrate and phosphate.

Some phytoplankton, like cocolithophores, develop shells made out of calcium carbonate (the same material as mollusk shells). For these organisms, calcium is a nutrient that is often in short supply. Other phytoplankton, like diatoms, produce shells made out of silica, which is also a nutrient that can be scarce in ocean water. Some other nutrients that are needed in very small quantities are iron, copper, magnesium, and zinc.

Temperature

With the exception of the hydrothermal vents (natural springs that vent warm or hot water on the seafloor) in the deep ocean, the range of temperatures in the ocean is much narrower than that found on land. Land temperatures vary from above 120°F (49°C) to well below freezing. Ocean water is rarely above 80°F (27°C) in tropical waters and never below 30°F (–1.9°C), as ocean water freezes at that temperature. Common water temperatures in temperate waters (waters that are not exposed to extremely cold or hot climates) are around 60°F (16°C).

Most animals—including most fish—that live in the ocean are ectothermic, which means that their body temperature is close to that of the water in which they live. The root word *ecto* means "outside" and the root word *therm* means "temperature." For these animals, their metabolic rate (the rate at which biochemical processes occur in an organism) is linked to the temperature of water in which the animal lives. For example, if two

Food Webs

Krill swimming in open ocean waters off Antarctica. *© Peter Johnson/Corbis. Reproduced by permission.*

The predator and prey relationships among organisms are termed food webs because the relationships are often drawn as diagrams with arrows connecting the prey and predators. When many different organisms are involved, the arrows begin to look like a web.

The amount of nutrients in the water relates to the complexity of the food web. In waters where there are few nutrients, phytoplankton grow slowly. Their predators, called primary consumers, are few. In turn, the primary consumers have few predators (secondary consumers). This type of environment is said to be oligotrophic (the root word *oligo* means "few" and the root word *troph* means "to eat"). The waters off of Antarctica are oligotrophic. There, the phytoplankton grow slowly because of low temperatures. Their primary consumer is the shrimp-like krill and the secondary consumers are baleen whales.

In waters where there are plentiful nutrients, there are many different species of phytoplankton and they all grow at different rates. This means that there is a variety of primary consumers and, in turn, a variety of secondary consumers. In fact, some animals may be both primary and secondary consumers. This type of food web is called eutrophic (the prefix *eu* means "true.") In eutrophic food webs, relationships between organisms can become complex and dynamic.

A process called eutrophication occurs when oligotrophic waters suddenly receive an input of nutrients. For example, in places where rain runoff from land contains fertilizers, the additional nutrients stimulate the growth of one species of phytoplankton that outgrows all other species. Sometimes these phytoplankton species clog the gills of fish or result in high growth rates of bacteria. Eutrophication is a serious problem that studies show is increasing, especially in coastal areas.

fish of exactly the same species and size are put in two aquariums, but one is three degrees warmer than the other, the fish in the warmer aquarium will eat more, have a faster heart rate, and swim faster.

Some fish and aquatic insects are endotherms (or, like tuna, are ectotherms that act like endotherms). Endothermic animals generate their own body heat via their metabolism (chemical reactions within the body). The root word *endo* means "internal." Endotherms can survive in environments that have a very large temperature range. This is demonstrated by whales that migrate from tropical regions to the frigid Arctic waters.

Hydrothermal Vents

In 1977, scientists from the Woods Hole Oceanographic Institute in Massachusetts discovered life surrounding hydrothermal vents in the deep ocean. The underwater craft *Alvin* dove to a depth of 10,000 feet (3,000 meters) near the Galapagos Islands. Equipped with a television camera, it returned images of the seafloor to a research ship on the ocean surface. The camera showed jets of very hot water (650°F; 350°C) bursting through the ocean floor. This water contained the mineral sulfur that caused the water to appear black and so the vents have been termed "black smokers."

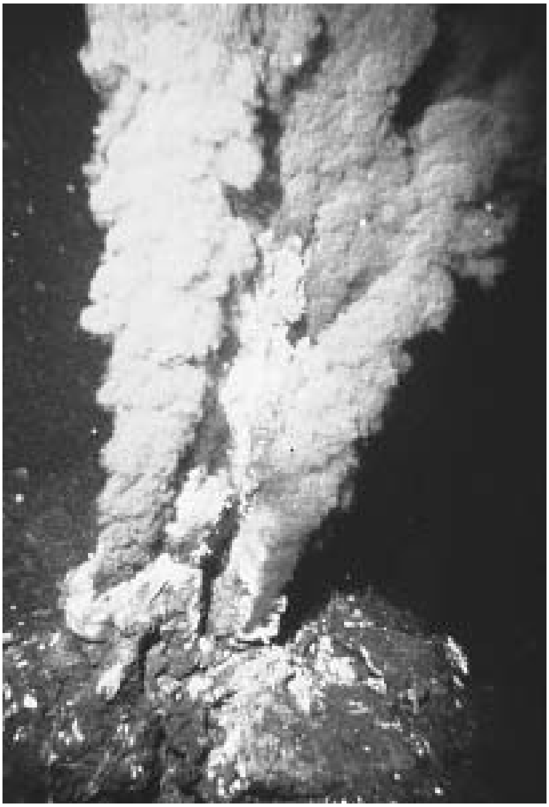
To the surprise of the scientists, the seafloor around the black smokers was not barren as expected; instead, groups of large marine worms were clustered around the vents. These worms lived in tubes and were about 12 feet (3.5 meters) long. This discovery was an incredible shock because biologists had assumed that no life could exist without photosynthesis, which depends upon energy from the Sun. Rather than relying on photosynthesis, these strange worms used energy from the chemical bonds in the sulfur to build their bodies.

The bodies of the hydrothermal vent worms, given the name *Riftia,* contain organs that house bacteria. The worms transfer dissolved sulfur out of the water to the bacteria that live inside their bodies. The bacteria then break the bonds of the sulfur molecule to provide energy to the worm. This process of using chemicals to provide energy is known as chemosynthesis. Since the initial discovery of the worms, several species of vent clams, *Calyptogena,* and some small shrimp have also been found living by chemosynthesis near hydrothermal vents. Since the first discovery by *Alvin,* many different vent communities have been found throughout the world.

However, endotherms require large amounts of food to provide the energy they need to keep their bodies warm.

Salinity Salinity is the amount of salt found in one kilogram of ocean water. The average salinity in the ocean is 35 parts per thousand (ppt). This means that there are 35 grams of salt per kilogram, or 1,000 grams, of ocean water. In places where rivers flow into the ocean or where there is a lot of runoff from rain, salinity can drop to 6 ppt. In places that receive little fresh water, such as the Red Sea, salinity can be greater than 40 ppt.

Most marine invertebrates have salinities within their bodies that are very similar to the salinity of the water around them. If the salinity of the water suddenly changes, then it can harm the animals by interrupting its natural osmosis. Osmosis is the tendency for the concentration of water to always be the same on both sides of a semipermeable barrier. (A semipermeable barrier allows some materials to pass through in both directions.) The cell barrier of an animal is semipermeable and water can easily flow through it. A change in salinity on the outside of cells will affect the concentration of the water inside cells. For example, if the seawater surrounding a squid suddenly becomes fresher, then osmosis will move water inside squid's cells. If this happens too quickly, the squid's cells can burst. On the other hand, if the squid suddenly moves to an area of high salinity, the water from inside the squid's cells will flow out into the environment. The cells will shrink and the squid could die.



A black-smoker hydrothermal vent near the Endeavor Ridge off the coast of California. *P. Rona. OAR/National Undersea Research Program (NURP)/National Oceanic and Atmospheric Administration. Reproduced by permission.*

Pressure At sea level, the pressure is 14.7 pounds per square inch (1 kilogram per square centimeter) or 1 atmosphere. This pressure results from the weight of the atmosphere (mass of air around Earth) pressing down on Earth. Most organisms on land do not notice this pressure since their bodies are built to push upwards with the same force. Water, however, is much heavier than air. For every 33 feet (10 meters) an organism descends in the ocean, an additional atmosphere of pressure is added.

Descending to great depths in the ocean is difficult for mammals because of the gas-filled spaces in their bodies. Sinuses and lungs, in particular, are filled with air that has a pressure of 1 atmosphere. These parts of the body collapse when the external pressure becomes too great. Humans can only descend to about 3 or 4 atmospheres (100–130 feet; 30–40 meters). Some whales, like the sperm whale, are able to descend to depths of 7,380 feet (2,250 meters). This is equivalent to a pressure of more than 223 atmospheres.

Most marine animals, like invertebrates and fish, avoid pressure problems by having internal pressures that are the same as those in their surrounding ocean environment. As a result they can move vertically in the ocean without much effect on their bodies.

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Sperm whales gather for mating. *© Amos Nachoum/Corbis. Reproduced by permission.*

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Coastlines

Coastlines are boundaries between land and water that surround Earth's continents and islands. Scientists define the coast, or coastal zone, as a broad swath (belt) of land and sea where fresh water mixes with salt water. Land and sea processes work together to shape features along coastlines. Freshwater lakes do not technically have coastal zones, but many of the processes (waves, tides) and features found along ocean coastlines also exist in large lakes.

Coastal zone features

All coastlines include a thin strip of land that is submerged at high tide and exposed at low tide, called the shoreline. The coastal zone, however, extends far inland from the shore, across lowlands called coastal plains, and far seaward to the water depth where ocean waves do not reach the seafloor. The coastal zone includes lagoons, beaches, estuaries, tidal wetlands, tidal inlets, river deltas, barrier bars and islands, sand bars, and other shallow-water ocean features.

- Lagoons: Shallow, salt-water bays between barrier islands and the mainland.
- Beaches: Sand deposits along shorelines. Intense waves wash fine-grained mud from coastal sediments (particles of sand, gravel, and silt) leaving only sand-sized grains of resistant minerals like quartz and calcium carbonate. Beaches are common on the seaward side of barrier islands where wave energy is intense.
- Estuaries: The mouths of rivers and streams that receive a pulse of saltwater with the tides.
- Tidal wetlands (flats): The broad areas of marshy wetlands around lagoons and estuaries that flood with salt water during high tides.
- Tidal inlets: Openings through which water and sediment are washed in and out of lagoons by daily tides.
- Deltas: Deposits of sediments at the mouths (ends) of rivers that flow into the ocean.
- Barrier bars and islands: Long mounds, or bars, parallel to the shore into which near-shore ocean currents carry and deposit sand. Eventually, some barrier bars grow tall enough to stay exposed at high tide and become barrier islands. The outer banks of North Carolina as well as

WORDS TO KNOW

Barrier island: A long, narrow, sandy island running parallel to the shore and separated from the mainland by a lagoon.

Carbonate: Rock or loose sed-iment composed of the mineral calcite or calcium carbonate.

Coastal zone: The shallow part of the ocean extending from the high-tide mark on land to the edge of the continental shelf.

Continental shelf: The submerged edge of a continent that slopes gently from the shoreline to the top of the continental slope.

Delta: Sedimentary deposit that forms at the mouth of a river.

Depositional coastline: A coastline formed from the sediment of carbonates, plants, and animals that have hard mineral shells made of calcium carbonate.

Erosional coastline: A coastline formed by rising tectonic plates that gradually wears away.

Estuary: A wide, funnel-shaped bay at the mouth of a river that is affected by ocean tides and where saltwater mixes with fresh river.

Lagoon: A shallow body of water that is separated from the sea by a barrier island or coral reef.

Reef: An underwater ridge of rock or coral near the surface of the ocean.

WORDS TO KNOW

Shoreline: A strip of land within a coastal zone that is submerged by high tide; also called shore zone.

Tectonic plate: A piece of Earth's crust that moves over geologic time, slowly changing the surface of the globe.

Galveston, Mustang Island, and South Padre Island in Texas are examples of barrier islands.

- Sand bar: A ridge of sand in rivers or along the coast built up by water currents.

Processes that shape coastlines

The coastal zone is constantly changing. Salt water rushes through tidal inlets into bays and estuaries twice daily. Waves, currents (steady flows of water in a prevailing direction), tides, and storms reshape coastal features over days, weeks, and months. Coastlines move landward and seaward as global sea-level rises and falls over hundreds and thousands of years.

All coastlines are at least somewhat affected by waves and tides. Waves straighten uneven shorelines by eroding (wearing away) points that extend into the ocean and depositing sediment in bays. They also generate strong, shallow currents that carry and deposit sediment parallel to the shore. Long shore-parallel features like barrier islands, spits (small strips of land that jut out into the sea), and sand bars border coasts where waves are the dominant force. Tides move sediment and water in and out across the shoreline, and tide-dominated coasts have features like tidal inlets, natural jetties (protective rock barriers), and funnel-shaped estuaries that form a 90° right angle to the shore. Most coastlines are shaped by both waves and tides, and have some parallel and perpendicular features.

Types of coastlines

All coastlines are affected by waves, tides, storms, and currents, and every coast includes a shoreline. There are, however, many different types of coastlines. Some coastlines receive large amounts of sand and mud from rivers. Others accumulate the skeletal remains of animals like corals and shellfish. In some places, waves are eroding coastlines that are rising from the sea.

Depositional coastlines Coasts that receive a steady supply of sediment are called depositional coastlines. Rivers like the Mississippi in the United States and the Nile in Egypt erode sediment from continental interiors and deposit it in huge deltas at their mouths. Waves, currents, and tides spread sediment into thin layers on the submerged continental shelf (the shallow seabed that stretches from the shore to the deeper ocean water). Over time, the weight of the sediment presses down on the edge of the continent, creating space for more sediment. New layers build on to the edge of the continent, and the coast moves seaward. Depositional coastlines typically encom-

Coastal Ecosystems

A starfish clings to rocks on a sandy beach. © *Craig Tuttle/Corbis. Reproduced by permission.*

The ecosystems that develop along coastlines depend upon the features of the coastline, including rocky shores, sandy beaches, mud flats, and estuaries. Each of these coastlines attracts different types of animals and plants and results in unique types of ecosystems.

Rocky shorelines are home to organisms that can attach themselves to rocks and withstand the great force of waves that crash on them. Plants often have strong root-like structures called holdfasts. Animals have streamlined bodies to reduce the pull of the water against them, enabling them to swim through rough water and avoid rocks. Animals like limpets, snails, and sea anemones flourish on rocky shorelines.

Sandy beaches and mud flats are home to burrowers (hole and tunnel diggers) like clams, crabs, and worms. They dig into the sand and extend filtering mouthparts to catch animals and plants that float by them. When the tide is out, these animals pull their feeding apparatus in and hide in the moist sand. Sea birds, like sandpipers, walk along the beaches pecking in holes in the sand for their diet of clams and worms.

Estuaries are regions where the water covers the surface for at least part of the year and controls the development of soil. These are places of great biological diversity because they provide so many different habitats for different animals and plants. A large number of invertebrates and fish spend at least some part of their lives in saltwater wetlands, especially when they are young. The many plants and the shallow waters provide protection for juveniles and the constant tidal changes bring in nutrients that cause plants to grow quickly. As a result, estuaries are often called the nursery grounds of the ocean.

pass a broad coastal plain, and a complex shoreline that includes long, wide beaches. These coastlines are almost flat, causing salt water to move far inland across coastal plains and up rivers during high tide. The Mid-Atlantic and Gulf of Mexico coasts of the United States are depositional coastlines.

Waves, tides, and currents sort and distribute incoming sediment into distinctive features along depositional coastlines. Some of these features include: barrier bars and islands, tidal inlets, lagoons, beaches, estuaries, and tidal wetlands.

Depositional coastlines also develop where plants and animals called carbonates live in clear, sunlit water away from river

Artificial Reefs

An artificial reef located off the shore of San Diego, California. © *Brandon D. Cole/Corbis. Reproduced by permission.*

In tropical (hot, humid) regions of the oceans, corals build colonies (groups) out of a hard material they produce called calcium carbonate. As corals grow on top of each other, they form giant reefs. Many invertebrates (animals without a backbone) attach themselves to these reefs and make their homes there. In turn, fish come to live among the reefs, feeding on invertebrates and hiding from predators in crevices. Large predators come to hunt on the reefs as well. Reefs become biologically diverse and important habitats.

In temperate (moderate temperature) regions, where the water is too cold for corals, reefs are much more scarce. (Corals tend to live in warmer waters.) However, as scuba diving and sport fishing has become more common, people have noticed that shipwrecks on the ocean floor serve as places of great biological diversity. Although these structures are "artificially" placed on the bottom of the ocean, the organisms come to live on them naturally. Whole ecosystems (community of organisms and their environments) develop on and in sunken ships. Invertebrates take advantage of the hard surfaces to form colonies and build homes. In turn, fish come to prey and hide from predators in these artificial reefs.

In the late twentieth century, several coastal states, including South Carolina and Florida, began developing programs to sink ships and other types of artificial reefs in their coastal waters. They wanted to encourage the biological diversity and the fishing that is associated with these communities. Many types of materials, like concrete bridges, aircraft, pipes, and dock platforms are also being sunk and used as artificial reefs. A few companies are even designing plastic and concrete habitats to be used as artificial reefs.

deltas. Carbonates like corals and shellfish have skeletons and shells made of the hard mineral calcium carbonate. The sediment supply on carbonate coastlines comes from the skeletal remains of the animals and plants that live there. Corals build giant ridges of rocks called reefs up from the seafloor. Florida and the Bahamas have carbonate coastlines.

Erosional coastlines Erosional coastlines occur where huge sections of the Earth's crust called tectonic plates lift out of the sea. These coastlines are common along far northern coastlines that are bouncing back after being weighed down by thick ice sheets, and along coasts where tectonic plates meet. Erosional

The land and sea breezes found near the shore usually provide excellent kite-flying winds. *© Tim Kiusalaas/Corbis. Reproduced by permission.*

coastlines are the norm in Maine and eastern Canada, along the west coast of North America, and in Scandinavia. Along these coasts, waves pound rocky shorelines and cut into the bottoms of cliffs. The shore retreats as blocks of rock and sediment fall into the sea. Isolated remnants of sea cliffs, called stacks, are left standing in the sea. All of these features are caused by movements of plates and wave action over time. The process of shoreline retreat claims much expensive real estate along erosional coastlines.

Life in the coastal zone

The plants and animals that live in the coastal zone have adapted to its cycles of change. Residents of tidal wetlands tolerate twice-daily drowning and drying. Fish in estuaries and lagoons adjust to large changes in water salinity (saltiness). Plants grow with their roots in salt water and can survive burial by shifting beach sand and river mud. Many ocean and land animals spend their early lives in coastal wetlands where there is shelter and plentiful food before moving to dry land or the open ocean as adults. Coastlines are also home to about two-thirds of Earth's human population. People continue to work to understand the nature of coastal zones in order to protect coastal populations from their hazards (storms, waves, floods, erosion), but also to protect coastlines from the damaging effects of everyday human activities, such as eroding sand dunes by climbing them, or generating pollution.

Laurie Duncan, Ph.D., and Juli Berwald, Ph.D.

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Currents and Circulation Patterns in the Oceans

The oceans are in constant motion. Ocean currents are the horizontal and vertical circulation of ocean waters that produce a steady flow of water in a prevailing direction. Currents of ocean water distribute heat around the globe and help regulate Earth's climate, even on land. Currents carry and recycle nutrients that nourish marine (ocean) and coastal plants and animals. Human navigators depend on currents to carry their ships across the oceans. Winds drive currents of surface water. Differences in temperature and salinity (saltiness) cause water to circulate in the deep ocean. The rotation of the Earth, the shape of the seafloor, and the shapes of coastlines also determine the complex pattern of surface and deep ocean currents.

Ocean water is layered. The shallowest water, called surface water, is warmer, fresher, and lighter than deep water, which is colder, saltier, and denser. The boundary between surface and deep water is a thin layer marked by an abrupt change of temperature and salinity. This layer, called the thermocline, exists in most places in the oceans. Surface and deep water only mix in regions where specific conditions allow deep water to rise or surface water to sink. Many organisms swim freely across the thermocline, and the remains of plants and animals continuously rain down through the deep water to the seafloor. However, most organisms live, or at least feed, close to the ocean surface where microscopic plants called phytoplankton float freely and absorb the sunlight they need to live. Very little light penetrates the surface water.

Surface currents

Earth's atmosphere (mass of air surrounding Earth) and oceans together form a "coupled system." Winds drive circulation of the oceans' thin upper layer of surface water, and temperature differences in the oceans help to generate atmospheric winds. Friction (resistance to the motion of one surface over another) between the moving air and the water surface pushes water in the direction of the blowing winds. Earth's eastward rotation causes currents to deflect (bend) to the right in the northern hemisphere and to the left in the southern hemisphere, a phenomenon called the Coriolis effect. Coriolis deflection causes clockwise circulation of wind-driven surface ocean currents in the northern hemisphere and counterclockwise circulation in the southern hemisphere.

Warm surface currents The subtropical trade winds, or trades, are strong, steady winds that blow warm water from west to east on either side of the equator (an imaginary line around Earth halfway between the North and South Poles), thereby creating west-flowing equatorial currents in the major oceans. The trades and equatorial currents push piles of warm water into the western halves of the Pacific, Indian, and Atlantic Oceans. Water flows down and away from the centers of the mounds, not unlike pancake batter spreading out on a griddle. The trades continue to push the water to the west, and Coriolis deflection guides it northward in the northern hemisphere and southward in the southern hemisphere. Warm, fast currents, called western boundary currents, flow away from the tropical warm pools toward the poles in the western halves of the ocean basins.

The Gulf Stream is the western boundary current in the North Atlantic. It flows north along the southeastern coast of the United States and then crosses the Atlantic on a diagonal path. Warm Gulf Stream waters create unusually mild climates

Coriolis effect: The effect of the Earth's rotation on the atmosphere and oceans that causes deflection to the right in the northern hemisphere, and deflection to the left in the southern hemisphere.

Current: The circulation of ocean waters that produces a steady flow of water in a prevailing direction.

Doldrums: A zone of dead air and still water, usually at the equator where the trade winds and equatorial currents converge.

Downwelling: Ocean zones where surface water sinks into the deep ocean.

Gyres: Large circular patterns created by surface water currents in the oceans.

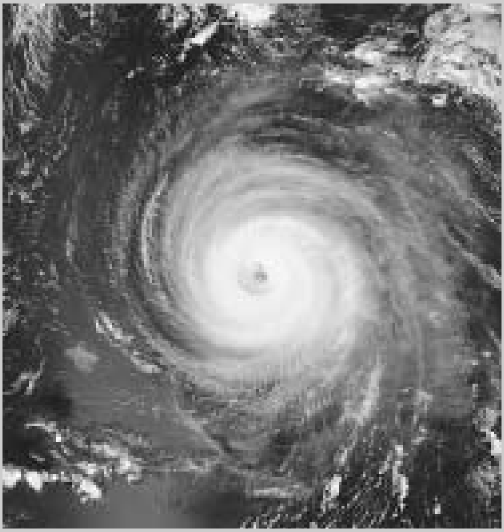
Phytoplankton: Microscopic plants that float in fresh or saltwater environments.

Salinity: A measure of the salt concentration of seawater.

Thermocline: A thin layer between surface water and deep water, marked by an abrupt change of temperature and salinity.

Upwelling: Areas in the ocean where cold, nutrient-rich deep water rises to the surface.

The Coriolis effect



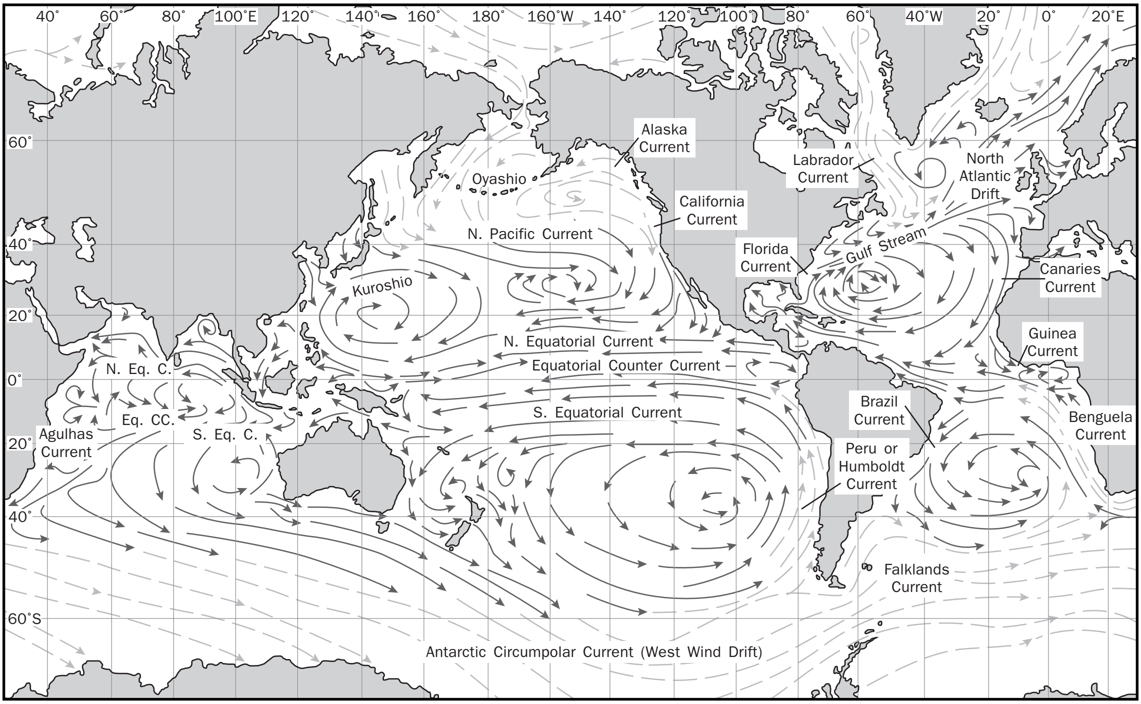
A photo taken from NASA's *Aqua* satellite captures the counterclockwise spin of Hurricane Isabel. The hurricane's central eye, around which the hurricane circulates, is shown approximately 400 miles north of Puerto Rico (September 2003). *© Corbis. Reproduced by permission.*

The paths of objects traveling on or above the Earth's surface are deflected to the right in the northern hemisphere and to the left in the southern hemisphere. This phenomenon, called the Coriolis effect, is named for French mathematician Gaspard-Gustave de Coriolis (1792–1843), who first explained it in 1835. Ocean gyres rotate clockwise in the northern hemisphere and counterclockwise in the southern hemisphere because of the Coriolis effect.

The Coriolis effect is sometimes called the Coriolis force. This is incorrect because nothing forces objects' paths to curve. The moving Earth is the frame of reference used to measure the route of a traveling object. A point on the ground at the equator has to move much faster to make its daily revolution than a point near the North or South Pole. Imagine an old phonograph record with a piece of graph paper glued to its surface. If you use a pencil to draw a straight line from the center of the turning record to its edge, the line drawn is a curve even though your pencil moved in a straight line. By the same token, the path of a missile fired straight from the North Pole toward the equator will curve to the east. Proper calculation of the Coriolis effect is very important for air traffic controllers and long-range missile programmers.

The Coriolis effect only creates a noticeable deflection for objects traveling long distances along north-south paths. The common myth that whirlpools and toilet flushes rotate the opposite directions across the equator is incorrect. A toilet is too small for the Coriolis effect to change the path of water in the bowl.

in northern locations. Gulf Stream waters keep Bermuda balmy, Ireland green, and England foggy. The Gulf Stream is the major shipping route from North America to Europe. The western boundary current in the North Pacific, called Kuroshio, likewise warms the islands of Japan and carries ships toward the Pacific Northwest. Western boundary currents in the southern hemisphere, the Brazil Current in the South Atlantic, East Australian Current in the South Pacific, and Aguellas Current in the Indian Ocean flow south from the equator.



A number of different ocean currents circulate in and through the world's oceans. *Thomson Gale.*

Cool surface currents Cold surface currents carry cool water from the poles toward the equator along the west coasts of the continents. The cool eastern boundary currents are generally shallower and weaker than the western boundary currents. Cold water flowing from the Arctic Ocean at the North Pole feeds the eastern boundary currents in the northern hemisphere, namely the California Current in the Pacific and the Canary Current in the Atlantic. The Antarctic Circumpolar Current (ACC) that encircles the ice-covered Antarctic continent supplies the cool water to the eastern boundary currents of the southern hemisphere—the Peru, Benguela, and West Antarctic Currents. The ACC is an exception to the general rule that surface currents are shallow. It extends from the sea surface to the seafloor in several places.

Gyres Surface water circulates in oceans in massive circular patterns called gyres. The major surface currents (eastern boundary, western boundary, and equatorial current) in each ocean link to form a circle. Gyres are clockwise in the northern hemisphere and counterclockwise in the southern hemisphere. For example, a rubber duck dropped into the ocean near San Diego might float south on the California Current to the North Equatorial Current, west across the Pacific Ocean to the

Kuroshio western boundary current, and then back across the northern Pacific to British Columbia. In a few years, the California Current might return the duck to San Diego. Ocean researches have actually conducted many such experiments. One important study tracked 29,000 plastic bathtub toys that spilled from a cargo ship in the North Pacific.

The infamous “triangle trade” between Europe, Africa, and North America in the eighteenth and nineteenth centuries relied on the North Atlantic Gyre. European slave ships arrived in Africa via the Canary Current, then carried slaves to the sugar plantations of the Caribbean on the North Equatorial Current. Having left off slaves and picked up sugar, they rode the Gulf Stream north to the rum distilleries of New England and the liquor shops in Europe. Hurricanes that form in the tropical Atlantic ride the North Equatorial Current toward the Caribbean Islands and then follow the Gulf Stream toward the southeast coast of the United States.

Deep ocean currents

Deep ocean currents are driven by differences in temperature and salinity. They are generally unaffected by surface currents. Deep water is colder, saltier, and denser than surface water. Deep water forms in polar regions where warmer surface water cools and sinks beneath the Arctic ice cap (permanent ice covering) or Antarctic ice shelves (permanent ice large enough to cover most of a land mass). Salinity increases near the ice caps because seawater forms freshwater ice when it freezes. The salt stays behind and the remaining liquid water becomes saltier. A “global conveyor belt” carries deep water south through the Atlantic, around Antarctica, and north into the Pacific, Indian, and Atlantic Oceans. It could take the molecules in a drop of water more than a thousand years to make a complete circuit of this global deep ocean current.

Upwellings and downwellings

Deep water rises to become surface water at upwellings. Upwellings are most common along coastlines where strong winds blow away from shore, but they also occur in the open ocean where winds blow away from one another. In both cases, winds push the warm surface water away and cold, nutrient-rich deep water rises to the sea surface to replace it. Upwellings are common along the west coasts of the continents, particularly in regions beneath the easterly (west-blowing) trade winds. Because they bring important minerals and nutrients from the deep ocean, upwellings typically support abundant marine and coastal life. Upwellings nourish waters rich with life off Peru, California, and southwestern Africa. A divergence between wind patterns creates a zone of intense upwelling that completely surrounds Antarctica.

Downwellings are ocean zones where surface water sinks into the deep ocean. Downwellings can occur at places were winds meet or blow toward shore. However, warm water does not sink, and warm surface currents are more likely to pile water up against obstacles like coastlines and opposing currents than to force it into the deep ocean. Most deep water forms at intense Arctic and Antarctic downwellings where ice cools the seawater and freezing increases its salinity.

Laurie Duncan, Ph.D.

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El Niño and La Niña

El Niño and La Niña are changes in the winds and ocean currents of the tropical Pacific Ocean that have far-reaching effects on global weather patterns. Together, El Niño and La Niña are extremes that make up a cycle called the El Niño Southern Oscillation (ENSO). An oscillation is a repeated movement or time period. El Niño and La Niña events do not occur in a regular or seasonal pattern; instead, they repeat about every two to seven years and last for a few months.

How El Niño and La Niña Occur

El Niño events occur when the trade winds and equatorial current south of the equator in the Pacific Ocean lessen in

WORDS TO KNOW

Equatorial current: A sustained pattern of water flowing westward near the equator.

Monsoon: A wind from the southwest that brings heavy rainfall to India and other parts of southern Asia during the summer.

Trade winds: Strong, constant easterly (west-blowing) winds on either side of the equator.

Tropics: Warm, humid region lying north and south of the equator.

Upwelling: An area where cold, often nutrient-rich water rises from the deep ocean to the surface.

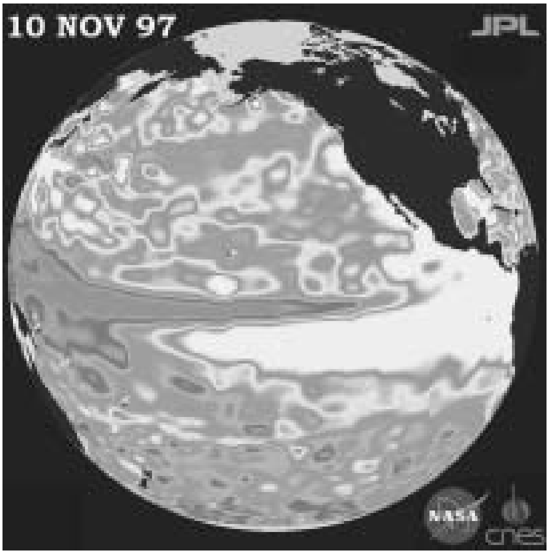
intensity. The trade winds, or trades, are strong, steady winds that blow from east to west and drive strong west-flowing ocean currents on either side of the equator. (The trade winds are named for their role in propelling sailing ships carrying cargo to trade around the world.) The equatorial current is a sustained pattern of water flowing westward near the equator. Less dramatic La Niña episodes occur during the opposite conditions, when the tropical winds and currents are unusually strong.

During normal, non–El Niño conditions, the trade winds and equatorial current in the southern Pacific push warm surface water to the west and allow cold water from the deep ocean to rise along the coast of South America. The southeasterly (northwest-blowing) trades south of the equator usually pile a mound of warm water around the islands of Indonesia, and create a zone of cool water that rises called an upwelling off the coasts of Peru and Ecuador. The cold, nutrient-rich waters of the South American upwelling nourish abundant microscopic plants (phytoplankton) and animals (zooplankton) that provide food for larger sea animals. It is a biologically rich region for fish and land animals, including humans who depend on fish for food. The pool of warm water in the western Pacific creates a warm, rainy climate, and the cold water of the upwelling causes an arid (extremely dry) climate in coastal South America.

Occasionally, for reasons not yet fully understood, the trade winds and southern equatorial current in the south Pacific lessen in strength. Warm water sloshes east toward the central coast of South America and shuts down the South American upwelling. The El Niño phase of an ENSO cycle begins with a dramatic warming of the waters off of South America and a decline of marine (ocean) life. La Niña, the opposite phase of an ENSO cycle, occurs when the southeast trades are particularly strong. La Niña events are marked by a strengthening of the South American upwelling and a good fishing season. La Niña events often, but not always, follow El Niño events.

Discovery of El Niño and La Niña

Peruvian fishermen who depended on the South American upwelling for their livelihoods recognized and named the El Niño phenomenon in the nineteenth century. The fishermen noticed that every few years, the seawater became much warmer and the pattern of ocean currents would change within about a month of Christmas day. These changes always marked the start of a very poor fishing season. Normally dry areas along the coast would receive abundant rain. As this typically happened close to Christmas, the fishermen dubbed the phenomenon El Niño, Spanish for "the boy child," after the Christ child. The other half of the ENSO cycle was named La Niña, "the girl child," much later.



Satellite photo of the Pacific Ocean taken November 10, 1997, shows sea surface height compared to normal ocean conditions. White areas show where the water is unusually warm, which is thought to cause El Niño weather patterns. *TOPEX/Poseidon, NASA Jet Propulsion Laboratory (JPL).*

El Niño has been a well-known local occurrence in coastal South America for more than 150 years. However, scientists only began to realize that the strong El Niño events were part of a disruption that effected the entire Pacific Ocean in the late 1960s. The effects of the southern oscillation were first recognized (and named) in the western Pacific by Sir Gilbert Walker in 1923. Walker was a British scientist who studied the changes in the summer monsoons (rainy seasons) of India. Using meteorological (weather-related) data, he observed that atmospheric pressure (pressure exerted by the air) seesaws back and forth from the Indian Ocean near northern Australia, to the southwestern Pacific near the island of Tahiti. Walker also noticed that the changes in pressure patterns were related to changes in the weather that affected rainfall, fishing, and agricultural harvests in Southeast Asia and India. In the late 1960s, Jacob Bjerknes, a professor at the University of California, first proposed that the Southern Oscillation and the strong El Niño sea warming were related.

Effects of El Niño and La Niña

The effects of El Niño on the climate of the tropical Pacific are now well known. As the mound of warm water in the western Pacific collapses and spreads eastward, the area of heavy rain above it shifts to the east. Fewer rain clouds form over the Pacific Islands, Australia, and Southeast Asia. Lush, biologically diverse rain forests dry out and become fuel for forest fires. Usually arid islands in the central Pacific receive heavy rainfall. In the eastern Pacific, the ocean upwelling weakens as the warm surface water flows toward South America. The surface water off Ecuador and Peru runs low on the nutrients that support the ocean food chain. Many species of fish and birds go elsewhere to find food, and human fishermen face economic hardship. The warmer waters offshore also encourage development of clouds and thunderstorms. Normally dry areas along the west coast of South America experience torrential rains, flooding, and mud slides during the El Niño years. La Niña events are usually less dramatic, but typically cause an opposite effect on the climate (long-term temperature, rainfall, and wind conditions) of the southern Pacific.

El Niño and La Niña also seem to cause far-reaching changes in the weather and climate in other parts of the world. The altered pattern of winds and temperatures in the tropical Pacific may change the paths of the jet streams (high-level winds) that steer storms across North and South America, Africa, Asia, and Europe. El Niños have been linked to mild, wet winters along the west coast of North America, strong storms in the Gulf of Mexico, heavy rains in the American Southwest, and droughts (lack of rain) in Central America and northern South America. In the El Niño years of 1986–87 and 1997–98, California and Chile both experienced torrential rainstorms and heavy snows that led to mudslides. El Niño may also affect the Indian monsoons and bring drought to northern Africa, thereby threatening agricultural harvests in India, Asia, and Africa. During La Niña episodes like 1998–99, the northern part of the United States may experience heavy snows, increased rainfall, and cold temperatures, while tornado activity increases in the southern states.

The far reaching climatic and economic effects of El Niño and La Niña make understanding ENSO a priority for scientists. Improved understanding and forecasting will help populations plan for the effects of El Niños and limit economic suffering and starvation. While El Niño and La Niña do have far-reaching effects, scientists are also careful not to blame *all* extreme or abnormal weather on the phenomenon, or to draw too many connections between Niño and global climate variations.

Laurie Duncan, Ph.D.

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Fish (Saltwater)

There are over thirty thousand different species of fish, and they are the most numerous vertebrates. Vertebrates are animals that have a bony spine that contains a nerve (spinal) chord. Vertebrates usually have an internal skeleton that provides support and protection for internal organs. This spine and skeleton allow vertebrates to move quickly and to have great strength.

Fish usually live surrounded entirely by water. They all have gills for breathing and fins for swimming. Most fish are ectotherms, which means that their bodies are nearly the same temperature as the water in which they live. About 60% of all fish live entirely in saltwater, while the rest live in freshwater or both freshwater and saltwater.

One of the most remarkable things about fish is their diversity. Fish can be very large, like the whale sharks that can reach 90,000 pounds (41,000 kilograms) or very small, like gobies that can weigh as little as 0.0004 ounce (0.1 gram). They have a variety of diets, including plants, other fish, invertebrates (animals without a backbone) and microscopic plankton (free-floating plants and animals). Fish find their food in many different ways, including hunting with their eyes, grazing, scraping the sea floor, and digging. Some fish have special organs that bioluminesce (create light) and lure prey towards their mouths, while others use this glow to make themselves blend in with coral or other ocean features, disguising themselves from predators. Fish come in a variety of colors that can serve to scare predators away or blend into their environment. Some fish live their entire lives within one bay or cove, while others may migrate thousands of miles (kilometers) across the ocean. Fish can live alone or they may swim with many other fish, called schools, to protect against predators.

WORDS TO KNOW

Cartilage: Tough but flexible material, found between bones in humans and in the skeletons of sharks and rays.

Dentricles: V-shaped structures that make up the rough skin of a shark.

Drag: A force that resists movement.

Ectotherm: An animal who maintains a body temperature that is nearly the same temperature as the water in which it lives.

Plankton: Animals and plants that drift with the currents.

Vertebrate: An animal that has a bony spine that contains a nerve (spinal) chord.

A school of blackbar sunfish pass a sunken plane off the shore of Jamaica. © *Stephen Frink/Corbis. Reproduced by permission.*

Fish are classified into three groups. The jawless fish belong to the class *Agnatha*. They include hagfish and lampreys. The rays and sharks belong to the class *Chondrichthyes*. They have skeletons that are made of a tough material called cartilage. The bony fish belong to the class *Osteichthyes*. This largest group includes many familiar fish like tuna, halibut, anchovy, and cod.

Class Agnatha

There are about fifty species of Agnathans and they are divided into two groups: hagfish and lampreys. These fish have no jaws and their fins are not evenly matched across their bodies, so they are not efficient swimmers. They have mouths that look like suckers with small teeth that are used for grasping on to prey. Organs for smelling and sensing surround their mouths and help them identify prey. These fish have very poor vision.

Hagfish live in colonies (groups) on the sea floor. They dig in sediments (sand, gravel, and silt) for worms to eat. If approached by predators, hagfish emit large quantities of foul-smelling slime from glands along the sides of their bodies. This usually discourages or confuses predators. After the danger has passed, the hagfish will tie itself in a knot, which it slides along the length of its body to scrape off the slime.

The mouth of the lamprey is called an oral disc. It is cone-shaped and contains sharp teeth that it uses to bore a hole into the side of another animal. The lamprey then attaches its oral disk to the live animal's wound and feeds off the blood and tissue of its host. Lampreys usually detach after some period of time without killing their host. Lampreys are usually most often found attached to bony fish, but they also have been seen on whales and dolphins.

Class Chondrichthyes

The class Chondrichthyes includes about 700 species of sharks and rays. They are an extremely old group, having been in existence for approximately 280 million years. Nearly all members of this class are marine (live in seawater). These fish have skeletons made out of cartilage, which is a tough but flexible tissue. It is the same material that is found in human ears and noses. Sharks and rays do not have gas bladders (internal sacs that fill with gas to help the fish rise or fall in the water so that it does not waste energy by continually swimming). Sharks and rays must continually swim in order to prevent themselves from sinking. However, the liver of sharks is large and it contains a lot of oily materials. As oil is less dense than water, this special liver helps the shark stay afloat. Cartilaginous fish have several rows of teeth that fall out as they age. They are then replaced with new teeth that grow in from behind.

Sharks do not have scales; instead they have rough plates called dentricles embedded in their skin. These dentricles make the skin feel abrasive, like sandpaper. Many sharks have electroreceptors on their heads. These specialized organs allow the shark to sense the electrical currents generated by fish as they swim through the water. The shark's

Sharks!

Although sharks are often portrayed as terrifying and terrorizing animals in the movies and in books, only a few species have ever been reported to act aggressively toward humans. Sharks are responsible for an average of about six human deaths and sixty attacks on humans per year around the world. As a comparison, dogs cause more than six hundred serious injuries to humans each year in the United States alone, and more than forty thousand deaths each year worldwide.

About 80% of all shark species are smaller than many people, less than 5 feet long (2 meters), and these species are unlikely to harm humans. Of the remaining 20% of shark species, three are most often involved with attacks on humans: the great white, the tiger, and the bull sharks. All three species are found throughout the world's oceans. They prefer large prey, like marine mammals and sea turtles.

The great white shark is responsible for more attacks on humans than any other shark. It is a member of the genus *Caracharodon,* which means "sharp tooth." It is actually not white, but rather a grayish color on top and a creamy color on the bottom. The great white shark can be as long as 23 feet (7 meters) and weigh 3,000 pounds (1,400 kilograms). After years of declining numbers from being hunted by humans, the great white shark is now a protected species along the coasts of California, Australia, and South Africa.

A great white shark with rows of razor sharp teeth that make it one of the most capable predators in the ocean. © *Amos Nachoum/ Corbis. Reproduced by permission.*

well-developed nervous system, including a large brain, also helps it locate its prey (animals that are food).

Rays have a more flattened shape than sharks. Their fins are attached to their bodies so that they look like triangular or semicircular wings. Large rays, like the manta ray, can measure 22 feet (7 meters) from fin to fin. These huge animals feed on plankton. Other rays, like the stingray, have sharp barbs attached to the base of their tail. These are used as defense against predators. Another family of rays can actually produce an electric current, which they can use to stun prey.

Class Osteichthyes

The class Osteichthyes, or the bony fish, make up the majority of fish, with almost 28,000 different species. These fish all have a strong, but lightweight, skeleton that supports their organs. They have gas bladders that help them maintain buoyancy. The teeth of bony fish are fused to their jawbone and do not fall out as do the teeth of the cartilinagous fish.

Osteichthyes are found in every type of marine environment from near-shore tidepools and coral reefs to the very bottom of the deep ocean. Nearly 90% of all the bony fish are categorized into one order, Teleostei. These fish include many common fish, like the cod, tuna, seabass, and perch. Teleostei also includes unusual fish like the mola, which floats near the surface of the ocean in warm currents; the angler fish, which lives on the seafloor and lures its prey using a worm-shaped appendage; and the football fish, which permanently fuses with its mate.

Movement Many teleost fish have bodies that are shaped to allow them to move easily through water. In particular, fast or constantly swimming fish have body shapes that minimize drag, or resistance to movement. The less surface area comes into contact with water in the forward direction, the less drag the fish will have. A torpedo shape, with a body that tapers towards the rear, is one of the most effective shapes for minimizing drag, and many fast-swimming fish have this sort of shape. An example of a fish with a shape that minimizes drag is the swordfish, which can reach speeds up to 75 miles per hour (120 kilometers per hour) in short bursts.

Some fish, like eels, wave their entire bodies back and forth in an "S" shape to move through the water. This is not a very efficient way of swimming as it requires a lot of energy and it increases the surface that confronts the water as the fish swims forward. More advanced swimmers have a stiff body, with a tail that bends back and forth behind the fish. This allows the fish to conserve energy because it only moves its tail, not its entire body. It also minimizes the area that confronts the water to the head of the fish.

Water and gas balance Just like humans, metabolism (the process of cells burning food to produce energy) in fish requires oxygen and produces carbon dioxide as a waste product. Fish breathe through gills, which are found underneath flaps on both sides of the head. Water containing dissolved oxygen is brought in through the mouth and pumped over the gills. The gills are packed with blood vessels that absorb the oxygen from the water and produce the carbon dioxide waste that is generated within the fish.

The body fluids of saltwater teleost fish are about one-third as salty as ocean water. Another way of thinking about this is that the concentration of water inside these fish is greater than the concentration of water in the ocean. Because of osmosis (the passage of a liquid from a weak solution to a more concentrate solution), the water from the inside of the fish is constantly diffusing (moving outward) from the fish. As a result, saltwater fish must regularly drink seawater to replenish the water that is lost by osmosis. The fish have special salt glands in their gills that remove the excess salt that comes inside the fish with the seawater.

Lateral line Teleost fish have developed an interesting sensory organ that helps to sense vibrations in the water. Along both sides of most teleost fish is a long row of canals (tubes) that are packed with nerve cells. These nerves detect movements of currents, changes in water pressure, and even noises.

Juli Berwald, Ph.D.

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Geology of the Ocean Floor

Geology is the study of the solid Earth and its history. Marine geology is the study of the solid rock and basins that contain the oceans. The rocks and sediments (particles of sand, gravel, and silt) that lie beneath the oceans contain a record book of Earth's past. Topographic features (the physical features of the surface of Earth) and geologic processes in the ocean basins hold the keys to plate tectonics, a fundamental theory of geology that explains the movement of the continents and seafloor over time. (A plate is a rigid layer of Earth's crust and tectonics is the large scale movements of the crust.) Only when scientists began to successfully probe the secrets of the seafloor in the mid-twentieth century did they begin to understand the complex workings of the solid Earth.

If marine geology is the study of the ocean soup bowl, then oceanography is the study of the broth, and marine biology is the study of the vegetables and meat in the broth. These three branches of ocean science are closely linked. The mountains and valleys of the seafloor, together with the continental margins (edges), act to guide ocean currents (a steady flow of water in a prevailing direction) that in turn regulate global climate. Moving water shapes the seafloor by eroding (wearing away) and depositing sediments (particles of gravel, sand, and silt). The seafloor provides shelter and nutrients (food) for marine (ocean) plants and animals, and living organisms play a role in shaping the seafloor. They burrow (dig holes and tunnels), build shelters, and consume nutrients during their lifetimes, and their remains form layers of sediment on the seafloor. Practical knowledge of seafloor topography (called bathymetry) and marine geology is essential for human navigators, coastal and marine engineers, naval tacticians, as well as petroleum (oil and gas) and mineral prospectors.

Depth and shape of the seafloor

Bathymetry beyond shallow coastal waters was a complete mystery until the middle of the 1800s. Until then, navigators used relatively short ropes and chains to make water depth measurements, called soundings, and to construct charts of shallow coastal waters where seafloor topography is a shipping hazard. By the 1860s, however, advances in science had raised a number of intriguing questions about the nature of the deep ocean floor. Royal Society of London naturalists aboard the ship *Challenger* used newly developed steel cables to take more than 500 soundings and to dredge 133 rock and sediment samples from the deep ocean during their expedition from 1872 to 1876.

The *Challenger* scientists discovered that the oceans are very deep. They took their deepest sounding in an ocean trench near the Mariana Islands in the western Pacific Ocean. Today, it is known that Earth's lowest point, the Challenger Deep in the Mariana Trench, is 36,201 feet (11,033 meters) below sea level. In comparison, Earth's highest point, the peak of Mt. Everest in the Himalayan Mountains, is a mere 29,035 feet (8,850 meters) above sea level! The average water depth in the main oceans is 12,200 feet (3,729 meters), deeper than the highest points in 38

WORDS TO KNOW

Abyssal plain: Vast, flat areas of the deep-ocean floor.

Basalt: Black iron- and magnesium-rich volcanic rock common in ocean basins.

Bathymetry: Three-dimensional shape of the seafloor; also called seafloor topography.

Echosounder: A tool that bounces sound waves off the ocean floor to record water depths or create maps of the ocean floor.

Lithosphere: Rocky outer shell of Earth that is broken into large, rigid pieces called plates.

Mid-ocean ridge: A continuous chain of low, symmetrical volcanoes that extends through all the ocean basins.

Pangea: A super-continent that existed about two hundred million years ago when all of Earth's continental land masses were joined.

Plate tectonics: Theory that Earth's plates move over time; explains geological patterns of earthquakes, mountain chains, volcanoes, and rock types.

Ring of fire: A zone of large volcanoes and earthquakes that surrounds the Pacific Ocean.

Seafloor spreading: The process by which a new oceanic seafloor is created by small volcanic eruptions at mid-ocean ridges.

Sediments: Particles of gravel, sand, and silt.

Subduction: The process by which an oceanic seafloor is recycled into Earth's interior at deep ocean trenches.

Plate Tectonics

Earth's rocky outer shell, the lithosphere, is broken into rigid pieces, or plates, that move over time. This fundamental theory of geology is called plate tectonics. It explains the jigsaw puzzle fit of continents across ocean basins as well as patterns of mountain ranges, earthquakes, volcanoes, and different types of rocks on Earth's surface. Plate tectonics also explains the observation that Earth's land masses have formed different patterns over geologic history, and have even been joined at times. Some plates, like the North American Plate, are composed of both continental and oceanic crust. Others, like the oceanic Pacific Plate, contain mostly one type of crust.

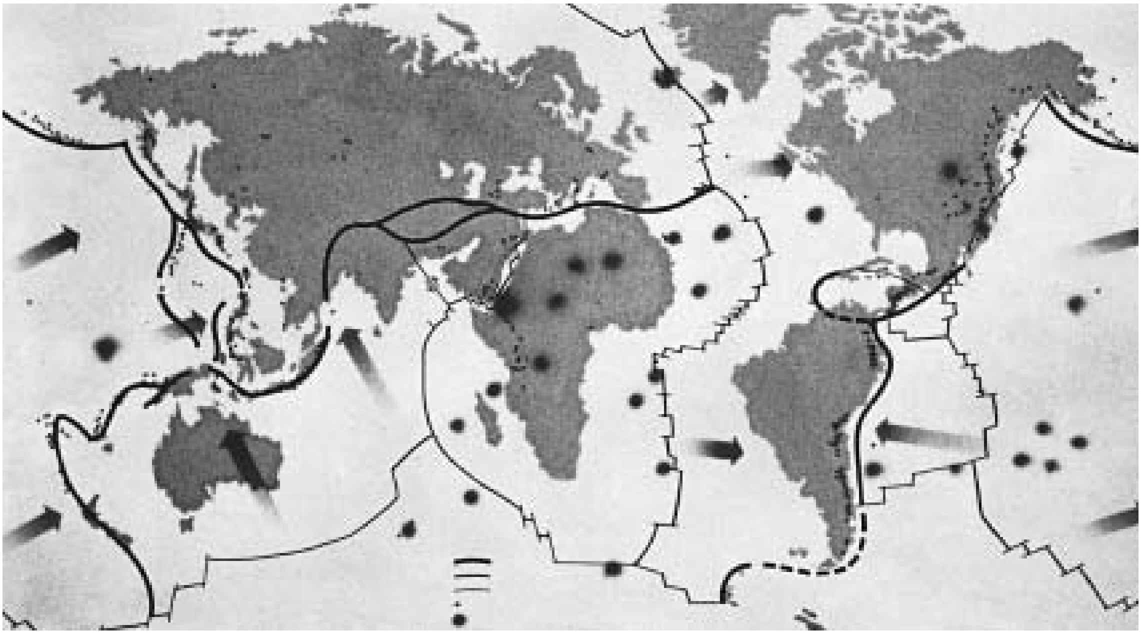
In 1912, German meteorologist Alfred Wegener (1880–1930) suggested that Earth's continents were joined about two hundred million years ago and have since drifted apart. Other scientists doubted him because he had no explanation for *how* the continents moved. (This was unfortunate because Wegener's theory of continental drift was correct.) The complete theory of plate tectonics was finally developed in the 1960s and 1970s by marine geologists studying new images and rock samples from the deep ocean floor.

Lithospheric plates move by processes that occur at their boundaries. There are three types of plate boundaries: divergent (plates move away from each other), convergent (plates move toward each other), and transform (plates move horizontally by each other).

Plates move about an inch (a few centimeters) per year, about the speed that fingernails grow. Places where oceanic and continental crust are connected and do not move relative to each other, like the east coasts in North America, are called passive margins. Passive margins are not plate tectonic boundaries. (The Mid-Atlantic Ridge in the central Atlantic Ocean is the eastern boundary of the North American Plate.)

of the 50 states of the union. Dredge samples from the *Challenger* expedition showed that ocean rocks and sediments are fundamentally different from those found on land.

In spite of the tantalizing clues turned up by nineteenth century British scientists, a full picture of the ocean basins did not come into focus until the late 1950s. In the early twentieth century, the spirit of scientific inquiry during the *Challenger* era was replaced by more practical reasons to map the seafloor—naval warfare during the first and second world wars. A new technique, called sonar echosounding, replaced expensive, relatively inaccurate wire soundings. An echosounder works by bouncing a sound wave off the seafloor. Sound travels at a constant velocity (speed) in water, so the time it takes for the sound to travel through the water and echo back to the ship gives the distance to the seafloor. The faster the sound returns, the shallower the water. American ships carrying troops and



Earth's tectonic plates move in response to forces generated deep within the Earth. *David Hardy/Science Photo Library. Reproduced by permission.*

supplies to Europe and Asia carried echosounders that recorded the water depths along their routes.

Civilian scientists were intrigued by what they saw on the wartime bathymetric profiles, and they set out to survey the seafloor using the new, accurate, inexpensive echosounders. The first complete maps of the Pacific, Atlantic, Indian, and Arctic Ocean basins were compiled by Columbia University marine geologists Bruce Heezen and Marie Tharp and published by the National Geographic Society in the mid-1950s. The features that were clearly visible on these bathymetric maps, globe-encircling chains of underwater volcanoes and deep ocean trenches, led to a revolution in marine geology and the theory of plate tectonics during the 1960s and 1970s.

Seafloor features

A bathymetric profile (cross-section) of a major ocean basin like the Pacific Ocean shows the typical features of the seafloor: continental shelf, continental slope and rise, mid-oceanic ridge, ocean trench, and abyssal plain.

- Continental shelf: Continental shelves are the relatively shallow, submerged margins of the continents. Some shelves, like the east coasts of North and South America, are very wide. Others, like the west coasts of North and

South America, are very narrow. Over geologic time, the shorelines on continental shelves retreat and advance as the ice in the North and South Poles grow and shrink and global sea-level rises and falls.

- Continental slope and rise: The continental slope is the steep transition from the continental shelf to the floor of the abyssal (deep) ocean. The slope is cut by huge canyons that carry underwater landslides, called turbidite flows, downslope at speeds of up to 40 miles (64 kilometers) per hour. The continental rise is the deposit of sediments at the base of the continental slope.
- Mid-oceanic ridge: The most striking feature of Heezen and Tharp's bathymetric map was the mid-oceanic ridge system, a continuous chain of low, symmetrical volcanoes that extends through all the ocean basins. A mid-oceanic ridge, like the Mid-Atlantic Ridge between South America and Africa, is a broad uplift with a small valley at its axis (center). Mild volcanic eruptions fill the ridge axis valley with molten lava that cools to become new seafloor. The ocean basins on either side of a mid-oceanic ridge are symmetrical mirror images that are moving away from the ridge axis over time.
- Ocean trenches: Trenches are deep, arc-shaped submarine valleys along the edges of the ocean basins. They are the deepest parts of Earth's oceans. Scientists now know that the moving seafloor is recycled into Earth's interior at trenches, a process called subduction. Chains of large volcanoes, called arc volcanoes, form on the outer edges of trenches. The Andes Mountains of South America and the islands of Japan are examples of arc volcanoes. Friction between rocks during subduction also causes very large earthquakes. The geologically active subduction zones that surround the Pacific Ocean are called the "ring of fire."
- Abyssal plains: The abyssal plains are vast, flat areas of the deep-ocean floor. In some places, small repeating sets of sharp-peaked ridges, called abyssal hills, interrupt the nearly featureless abyssal seafloor. Cross-sections through the seafloor show that abyssal hills are the tips of tilted blocks of rock beneath a blanket of deep-ocean sediment.

Ocean rocks and sediments

The solid rock, called the basement, that acts as the floor of the deep ocean is different from that of the continents. Earth's rocky outer crust comes in two varieties, continental and

Tsunamis

Men survey damage after a 1946 tsunami struck the shore of Hilo, Hawaii. *National Oceanic and Atmospheric Administration. Reproduced by permission.*

Tsunamis are ocean waves caused by disturbances on the seafloor. Underwater earthquakes, volcanic eruptions, landslides, and man-made explosions create these very large waves that travel great distances across ocean basins. Tsunamis are particularly common in the Pacific Ocean where large seafloor earthquakes and volcanic eruptions occur regularly around the "ring of fire." The largest earthquake of the twentieth century occurred in 1960 in the Peru-Chile Trench offshore of South America. It triggered a tsunami that traveled throughout the Pacific Ocean. The huge waves caused widespread destruction and killed 231 people when they washed ashore at the Hawaiian Islands, the west coast of the United States, Japan, and the Philippines.

The word *tsunami* means "harbor wave" in Japanese. In the open ocean, tsunami waves are very broad, but not very tall. When they approach land, the waves get shorter and much taller; they appear to spring up from the ocean near coastlines. Tsunamis are sometimes mistakenly called tidal waves because an approaching tsunami can resemble a rapidly falling and then rising tide. (Tides are daily sea level rises and falls.) Tsunami waves can be as tall as a six-story building and are very unpredictable; they are not generated by wind like most ocean waves, and can arrive from distance sources during calm weather conditions.

oceanic, that have very different properties and compositions. Ocean crust is denser, thinner, darker-colored, and contains more of the chemical elements iron and magnesium than continental crust. The basement of the ocean basins is mostly made of black, volcanic rock called basalt. Mid-oceanic ridge volcanoes produce basalt. The centers of the continents are composed mainly of coarse-grained, light-colored rocks like granite. The blanket of sediment that covers the floors of the abyssal plains is called pelagic ooze. Oozes form by the slow, steady accumulation of silica- and calcium-rich remains of microscopic animals and plants that sink to the deep seafloor.

The boundary between deep ocean rock and continental land rock lies beneath massive fans of sediment that form the continental margins. Continental margins, including the continental shelf and slope, are composed of thick stacks of layered sediment that rivers and glaciers have carried from the continental interior. Some shelves, called carbonate shelves, are composed of the calcium carbonate shells and skeletons of organisms like corals and mollusks. Along many continental margins, continental sediments gradually give way to pelagic oozes at the toe of the continental rise.

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Islands

Islands are land areas smaller than a continent that are completely surrounded by water. Islands range in size from islets (small islands) barely exposed at high tide, to vast landmasses almost the size of continents. Islands exist in all the ocean basins (the deep part of the ocean floor), along coastlines, and in freshwater lakes and rivers. Islands come in many sizes and shapes, but they all share the same defining characteristics. There are more similarities than differences between a huge arctic island like Greenland and a small tropical one like Guam.

Islands are isolated. The water around them controls their climate and weather. The British Isles, which include Great Britain and Ireland, have a mild climate for their northern location because they lie in the path of the warm Gulf Stream current (a current is a steady flow of water on a prevailing direction). The Galapagos Islands, located on the equator in the Pacific Ocean, are kept surprisingly cool due to the rising of cold water from the deep ocean. Islands have limited areas for catching rainwater or snow, and fresh water is generally scarce, particularly on small islands in arid (extremely dry) areas. The majority of islands are remote and difficult for land plants and animals to reach. They often support unique ecosystems (groups of organisms that live in a particular environment) that have evolved (changed over time) with little influence from surrounding areas.

Geologic (natural Earth processes) activities form islands through various ways, including by raising a piece of seafloor above the water surface, or by separating an area of land from the edge of a continent. Volcanoes and corals (small crustacean animals that live in shallow parts of the ocean, building coral reefs with their shells) both construct mounds on the seafloor that can become exposed islands. Chunks of land can be separated from continents. When the global sea level rises or falls because of melting and freezing of ice on the North and South Poles, islands can be exposed or submerged. Islands also sink below sea level under the weight of volcanic lava flows or ice, and rise when the rock is naturally worn away from their surfaces. Many islands form by a combination of these geologic processes.

Volcanic islands

Many islands are the exposed peaks of active and inactive seafloor volcanoes. An active volcano is one that has erupted in the past and is likely to do so again; an inactive volcano is no longer likely to erupt. Chains of volcanic islands, including the Aleutian Islands, Japan, the Philippines, and the Solomon Islands form the "ring of fire" that surrounds the Pacific Ocean. These island chains, called volcanic arcs, lie along plate tectonic boundaries, where one massive plate of Earth's outer layer is sinking beneath a second plate, in a process called subduction. (Plate tectonics is the theory that Earth's rocky outer layer is broken into pieces, or plates, that move over time.) The islands of Indonesia and Borneo lie over a subduction zone in the northwestern Indian Ocean. Cuba, Hispanola, Puerto Rico, and the Lesser Antilles are volcanic arcs in the Caribbean Sea.

WORDS TO KNOW

Atoll: Ring-shaped coral island that surrounds a shallow lagoon.

Barrier Island: Long, narrow coastal island built up parallel to the mainland.

Carbonate: Rock that is made of calcium or magnesium carbonate, such as limestone, coral, and dolomite.

Continental margin: The area between a continent's shoreline and the beginning of the ocean floor.

Coral: A rocklike deposit formed of the calcium carbonate skeletons of a group of small sea animals.

Guyot: A flat-topped submarine mountain.

Lagoon: A shallow body of water that is separated from the sea by a reef or narrow island.

Lava: Hot, liquid rock that reaches the Earth's surface through a volcano or opening in Earth's crust.

Plate tectonics: The theory that Earth's lithospheric plates move over time. It explains geological patterns of earthquakes, mountain chains, volcanoes, and rock types.

Seamount: An underwater mountain.

Crater cone at the center of a volcanic island. © *Yann Arthus-Bertrand/Corbis. Reproduced by permission.*

Other types of volcanoes also build islands and seamounts. (A seamount is an underwater mountain whose peak does not extend above the water surface. Most seamounts are volcanoes that never grew tall enough to become exposed islands, but some are former islands that have been submerged by rising sealevel or their own sinking.) Sicily in the Mediterranean Sea, Catalina Island off southern California, and the remote Kerguelan Islands in the southern Indian Ocean are also volcanic islands. Some islands are created from hot spot volcanoes. A hot spot is a stationary heat source under a moving tectonic plate. As the plate moves over the hot spot, a line of volcanoes forms above it. The Hawaiian Islands, Iceland, and more than six hundred small islands in the southwest Pacific Ocean are hot spot volcanoes.

Coastal islands

Erosion (wearing away of material by natural forces) and deposition by nearshore currents and waves shape sediment (sand, gravel, and silt) into islands along coastlines. These processes can form barrier islands, which are long, narrow coastal islands built up parallel to the mainland. Barrier island chains border the edges of continents that receive large amounts of sediment from rivers. In the Gulf of Mexico, a strong current has built a continuous chain of barrier islands along the coasts of Texas and northern Mexico by dragging sediment away from the Mississippi River Delta. Tides cut narrow strips of water in the land that separate the sandy barrier strip into islands and carry water into the lagoons (a shal-

Hawaiian-Emperor Seamount Chain

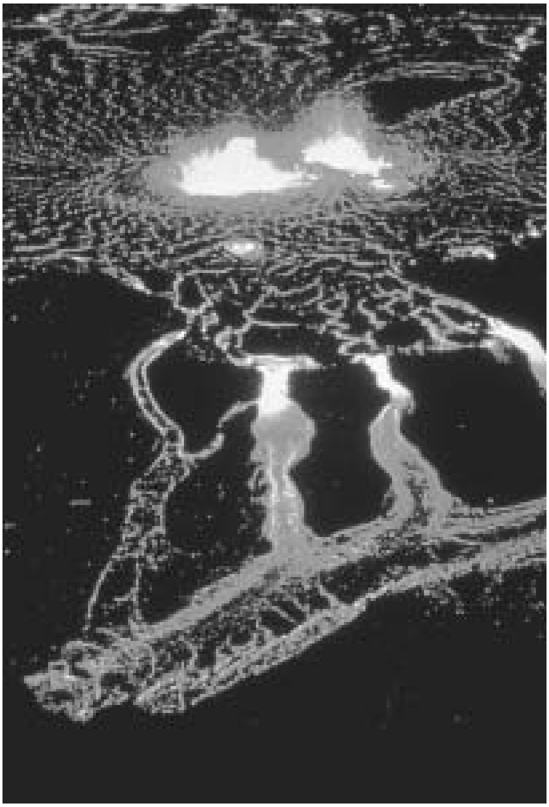
The beautiful, remote Hawaiian Islands are the newest additions to a line of volcanic islands and seamounts that extends thousands of miles across the Pacific Ocean seafloor. An unmoving heat source deep in Earth's interior, called a hot spot, created the volcanoes of the Hawaii-Emperor chain. Like a sewing machine needle punching holes in a piece of fabric, the hot spot has melted holes in the overlying Pacific Plate moving above it. (The Pacific Plate is a massive piece of Earth's outer layer that is moving to the northwest at about the same speed that hair grows, about one-half inch per month.)

In 2004, the hot spot lies under the Big Island of Hawaii. It supplies the hot liquid rock to three active volcanoes (Mauna Loa, Kilauea, and Hualalai) that are presently adding lava flows to the surface of the island. (When measured from its base on the seafloor, Mauna Loa is Earth's tallest and most massive mountain. Its base covers an area about the size of Connecticut.) A fourth active volcano, Loihi, is erupting on the seafloor just south of the Big Island. In the future, the northwestward motion of the seafloor will carry the Big Island away from the hot spot, its volcanoes will become inactive, and a new island will form as Loihi's eruptions build its peak above sea level.

The age of the Hawaiian-Emperor volcanoes increases to the northwest. Once a volcano has moved away from the hot spot, it begins to cool and sink into the seafloor. Erosion by rivers and waves level its surface, and a ring of coral forms around its edge. Eventually, the center of the island sinks below sea level, but the coral keeps growing, creating a ring-shaped island called an atoll. (Charles Darwin first proposed this theory after observing atolls in the South Pacific.) Finally, when the island has sunk too far for sunlight to reach the corals, it becomes a flat-topped seamount with a crown of coral. Many of the Emperor seamounts are flat-topped volcanoes called guyots and some of them are former atolls.

The Hawaiian Islands, Hawaii, Maui, Lanai, Kahoolawe, Molokai, Oahu, Niihau, and Kauai, live up to their reputation as a paradise on Earth. Beautiful, fragrant plants thrive in the lush, tropical climate. (Hawaii is an exception to the general rule that islands are dry; its islands are fairly large and have high volcanic peaks that extend into the path of moisture-bearing winds. Mt. Waialeale, on the oldest Hawaiian island of Kauai, is the wettest place on Earth. It receives about 400 inches or 1,016 centimeters of rain each year.) The shallow waters around the islands support diverse sea life, and migrating sea animals like whales stop there to feed, mate, and impress tourists.

low area of water separated from the ocean by a coral reef or sandbar) between the islands and the mainland. Barrier islands like North Carolina's Outer Banks and South Padre Island in Texas are essentially large sandbars (long strips of sand) that are constantly being reshaped by currents, waves and winds. A large hurricane can completely destroy a barrier island—houses and all—and reshape the sediment into a new island within a few days.



Lava spewing from Kilauea volcano in Hawaii runs seaward. *JLM Visuals. Reproduced by permission.*

Not all barrier islands and coastal islands are made of sand. The Florida Keys and barrier islands of northeast Australia are reefs that fringe continental shelves (the edge of land that slopes into the sea) away from major rivers where corals grow in clear waters. Long Island, Nantucket, and the other islands off southern New England are huge piles of rock fragments and boulders left by glaciers (large masses of moving ice) that retreated at the end of the last ice age about twenty thousand years ago. Some coastlines, like those of Maine, northern California, and Norway are rising from the ocean because of shifting tectonic plates on Earth. Islands off these rising coasts are fragments of sea cliffs and rock that resisted erosion toward the mainland.

Big islands: continental fragments

The movement of tectonic plates breaks the continents into pieces that move across the Earth surface. Many of Earth's largest islands are blocks of continental crust that split from the main continents. Madagascar, for example, is a large island in the Indian Ocean that separated from the east coast of Africa. Greenland, New Guinea, and Tasmania are also broken continental blocks. India was a very large island until it collided with Asia about forty million years ago.

Carbonate Islands

Some islands were at least partially constructed by animals. Many marine organisms including corals, mollusks, and gastropods have skeletons and shells composed of a mineral called calcium carbonate. Limestones and other rocks that form from the remains of these animals are called carbonates. The soft, white beaches of some of the world's most beautiful islands—Tahiti, Hawaii, the Bahamas, Bermuda, and Bali to name a few—are composed of the carbonate remains of lagoon and reef species. Corals are carbonate organisms that build elaborate community structures, called reefs, up from the seafloor. A reef is like an apartment building where each resident builds his own unit. When an individual animals dies, their "apartment" is vacant but still standing, and living corals continue to build the reef upward.

Trickles of water run down the sides of Mt. Waialeale Crater in Hawaii, a chain of volcanic islands. © *Michael T. Sedam/Corbis. Reproduced by permission.*

Carbonate species generally require clear, shallow water to thrive. Coastal carbonate islands, like the Florida Keys, only develop away from river deltas (where rivers meet the sea) where the water is too muddy. Carbonate islands away from coastlines usually have a volcanic or continental structure that provides an area of shallow water for light-loving species. The islands of the Bahamas, for example, are the exposed spines of coral reefs that cover a large block of seafloor that was uplifted by plate tectonic forces about 200 million years ago. The Bahamian platform is sinking under the weight of its surfacing limestone layers, but the corals built the reefs up to the sunlight. Volcanic islands like Hawaii and Tahiti are typically surrounded by a ring of reefs and a shallow lagoon that host numerous carbonate species. This explains, among other things, how islands of black volcanic rock can have white beaches.

Island life

Islands are remote. Island plants grew from seeds carried by birds. Some animals walked to islands on exposed land bridges when the sea level was lower during the ice ages, and others rode away from their home continent on a moving chunk of land. However they first arrived, island plants and animals live in closed ecosystems where they interact only with each other. (Some island ecosystems are, of course, more closed than others. The difficulties of reaching a barrier island across a lagoon are much less than those of reaching a volcanic island at the center of a huge ocean basin.) Throughout most of Earth's history, plants and animals that lived on islands are descendants of organisms that swam, floated, or rode there in the past. Today, humans sail, fly, and take man-made bridges to almost all of Earth's islands, and they bring plants and animals with them.

Islands often are homes to extremely rare species that are unique to their island or group of islands. Charles Darwin's (1809–1882) observations of the rare species of the Galapagos Islands inspired his theory of evolution in 1835. He theorized that new species evolve by combinations between individuals with different traits. Organisms with the traits best suited to its environment will flourish and reproduce, causing these traits to be continuously passed to offspring. Individuals with traits less suited to their environment will not survive and eventually die out. On islands, the number of individuals and species is limited and changes happen more rapidly. Furthermore, because new types of species arrive infrequently, the species that evolve on an island can be totally unique. The Galapagos Islands are home to Earth's only swimming iguanas as well as huge tortoises that can live for two hundred years.

Island organisms also evolve to prey on and protect themselves from only the plants and animals on their island. They have no defense mechanisms from non-native predators and little immunity to foreign diseases. When species arrive from afar, island species can suffer. Humans have been particularly destructive to island species because they are predators themselves, and they import many non-native plants, animals, and diseases. For example, humans brought snakes to Pacific Islands like Guam and Hawaii that decimated the endemic (native) birds and mammals. Humans then imported mongooses to kill the snakes, and the mongooses proceeded to kill not only snakes, but also a large number of the remaining island species. Today, many island governments and conservation groups are attempting to restore endangered island ecosystems.

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Kelp and Seaweed

From the tiniest of bacteria to the massive blue whale, the world's oceans and freshwater support a tremendous variety of life. Often, a beachcomber will find rubbery plants washed up on the shoreline. These exotic-looking plants are seaweed. A dive below the surface of coastal waters in some areas of the world, such as California, reveals a world of towering plants that sway gently in the ocean current. These giants are one form of seaweed called kelp.

Kelp make up only about 10% of all the known seaweed species. The many varieties of seaweed present in the world's fresh- and saltwater provide a habitat and even a food source for creatures. Humans benefit from seaweed as well. For thousands

WORDS TO KNOW

Agar: A mixture of sugars found in some types of seaweed that can form a solid surface used in laboratories to grow bacteria.

Algae: Fresh and salt water plants that can convert the Sun's energy into food; they range in size from microscopic cells to forms that are bigger than a person.

Frond: A long, feathery leaf, or the blade of a kelp plant or sea plant.

Holdfast: The part of a seaweed that allows the plant to attach to a rock.

of years in Far East countries like Japan, seaweed has been an important part of the diet, in the form of soup stock, seasoning, and as an integral part of sushi. In addition, seaweed is useful in the laboratory. The artificial growth surfaces used to raise bacteria rely on a seaweed component as a thickening agent, similar to that found in gelatin.

Characteristics of seaweed

The leafy-looking seaweed that grows in ocean waters is a type of algae. Other forms of seaweed look grass-like or feathery. Algae are plants; that is, they contain the chemical chlorophyll that converts energy from the Sun into food substances that the plant uses to grow. Algae range in size from microscopic single cells (the fundamental unit of all living things) to huge numbers of cells assembled together to form a much bigger organism. Seaweed is the large collection of algae cells, or macroalgae.

The many types of seaweed come in all shapes, sizes, and colors. Depending on the species, shapes range from the mighty tree-like kelp to the smaller and more delicate leafy or ribbon-like seaweed varieties. Most types of seaweed are found in shallow water, from just a foot or so to depths of 100 to 200 feet below the water's surface, as it needs sunlight for growth. Also, most seaweed is found where there are rocks, as the seaweed clings onto the rock at one end using a structure called a holdfast. Some seaweed can attach to the sandy ocean bottom using a specialized structure that appears similar to the roots of plants that grow on land.

Like plants, seaweed can convert the energy from sunlight into the compounds needed for its growth. In order words, seaweed is a photosynthetic organism. Some seaweed contains the light-absorbing compound chorophyll, which gives seaweed its green color. Other species of seaweed contain different light-absorbing chemicals that are colored red, brown, blue, or gold.

While similar to land-bound plants in its light-absorbing ability, seaweed is distinct from its land cousins in other ways. It can contain a holdfast, a part that anchors it to the seafloor. Many types of seaweed also have hollow, gas-filled structures called floats that help buoy the leaves up nearer to the sunlight.

The three categories of seaweed

Seaweed is often grouped into three categories based on its color. These groups are the brown, green, and red algae. Brown algae range in size from forms that are a few inches (centime-

Workers collect edible seaweed on the coast of Hokkaido Japan's Cape Kamui. © *Michael S. Yamashita/Corbis. Reproduced by permission.*

ters) in size to the giant kelps that can reach over 150 feet (46 meters) long. This type of seaweed lives only in salt water, and cannot grow in waters where the temperature varies much. Brown algae is found in waters that stay cold all year, such as the coastal waters of Alaska, or in tropical waters that stay warm all the time.

The chemicals that make up brown seaweed are useful in the manufacturing of cosmetics and some medicines. For example, kelp can be used in medicine to treat high blood pressure, thyroid problems, and even arthritis. Seaweed is also a rich source of such minerals as iodine, zinc, copper, sodium, calcium, and magnesium, which are important in a healthy diet. Additionally, brown seaweed has been an important part of the Japanese diet for centuries; it is used in soups, as an additive to change the taste of other foods, and as a wrap for the raw fish and rice combinations known as sushi.

The red algae group dominates in ecosystems such as coastal regions of California, where they can comprise 70% of all the seaweed species present. The group contains about 3,800 dif-

Giant Kelp (Macrocystis)

The giant kelp forests that grow off the coasts of Australia and California are made up mostly of a type of kelp called *Macrocystis pyrifera.* Macrocystis can grow up to 100 feet (30 meters) long, and growth of several inches (centimeters) every day is not uncommon.

Giant kelp forests off the coast of Australia and Tasmania are diminishing due to pollution, climate change, and the growing numbers of hungry sea urchins (invertebrate organisms that are related to sea stars but that are ball shaped and protected by long, sharp spines) that feed on kelp. Sediment (particles of sand, silt, and soil) and chemicals that flow off of land (runoff) and sewage interfere with the reproductive process of kelp. When waters are cooler, sea urchins off the eastern coast of Australia are passive feeders, meaning they eat smaller species that drift near to them. When the water warms, however, sea urchins become hearty kelp eaters. Since 1994, the waters off the coast of eastern Australia and Tasmania have warmed by about 3°F (1.7°C), and sea urchins have eaten vast areas of kelp forests.

One of the greatest kelp losses occurred off the coast of northeastern Tasmania, which is bathed by the warm waters of the East Australian Current. In the 1950s, California solved a similar problem of dwindling kelp forests by encouraging a sea urchin fishing industry and introducing runoff and sewage control measures. The California kelp forests returned by the mid-1970s.

ferent species of seaweed. Because they can absorb even tiny amounts of sunlight, red algae can live deeper in the water than other kinds of seaweed. Many red algae can live at depths of 150 to 200 feet (46 to 61 meters) below the ocean surface, and some species have been found growing even 600 feet (183 meters) below the surface of the ocean. At these depths, the ocean waters are calmer, and the red algae that live there tend to have a more delicate structure. These algae are more easily broken than seaweed that grows in the churning waters nearer to the surface. A component of red algae is also used to make the solid food (agar) that is used in laboratories to grow many types of bacteria.

Green seaweed can be found in both freshwater and the ocean. These types of seaweed feed on water that contains chemicals such as nitrogen and phosphorus that flow into the water from farmer's fields, or that are in sewage. When some types of green algae are present in high concentrations, this may indicate that the water is polluted with too many of these chemicals.

Kelp

Kelp are a type of brown seaweed that often appear as big leaves swaying in the underwater current. Some types of kelp can grow to be almost 100 feet (30 meters) long, and can form an underwater forest. Kelp are important to life in the sea. The thick masses of kelp that grow off the coasts of New York, California, Australia, the Arctic, and the Antarctic are home to a variety of creatures including lobsters, snails, octopuses, seahorses, starfish, fish, and seals. These sea creatures use the seaweed forests as a protective haven as well as a source of food. Thus, kelp is important in establishing and sustaining the complex ecosystems that can form.

A kelp plant can grow to be dozens of feet (meters) long and grow quickly. It is anchored to the bottom of fairly shallow waters by means of a holdfast and reaches up toward the sur-

A diver is dwarfed by surrounding giant kelp that waves in the ocean current. © *Amos Nachoum/Corbis. Reproduced by permission.*

face, forming an underwater forest. The leaf-like structures (fronds) that are near the surface have pockets of air built into them, which act as balloons to hold the leaves nearer to the surface where they can capture the Sun's energy.

The material that makes up kelp is also part of peoples' everyday lives. Kelp helps thicken ice cream and jelly, and provides the smooth texture present in some frozen drinks.

Brian Hoyle, Ph.D.

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Layers of the Ocean

Oceanographers (scientists who study the oceans) often divide the ocean into horizontal layers. They use the physical characteristics of the water such as temperature, density, and the amount of light at different depths to classify these layers. The most important factor is the density of the water, which is determined by the combination of salinity (the amount of salt in the water) and temperature. All ocean water is salty, but some contains more salt than others. The water that is saltier is heavier and sinks, while the water that is less salty is lighter and floats. Similarly, warmer water is lighter than colder water, so it floats on top of colder water.

Oceanographers generally categorize the ocean into four layers: the epipelagic zone, the mesopelagic zone, the bathypelagic zone, and the abyssopelagic zone. The word "pelagic" refers to the open ocean, away from the coast. The prefix *epi* means "surface"; the prefix *meso* means "middle"; the prefix *bathy* means "deep"; and the prefix *abysso* means "without bottom." In addition, the transition zone between the epipelagic and the mesopelagic is often called the thermocline.

Epipelagic zone

The epipelagic zone refers to the surface of the ocean where light penetrates. This layer is also called the photic zone, referring to the light that is found at these depths. Light is extremely important in the ocean. Just like plants on land, phytoplankton (free-floating plants, generally microscopic) require light to grow. Phytoplankton are the base of the food web (the network of feeding relationships in an ecosystem) in the ocean; they produce food by converting the energy from the Sun into energy they need to live and grow. When phytoplankton are eaten by zooplankton (free-floating animals) and fish, this energy is converted into the materials in their bodies. This transfer of energy continues as each predator (an animal that hunts, kills, and eats other animals) eats its prey (animals that are hunted and eaten by other animals), but it all begins with the energy from the Sun.

Sometimes the photic zone is referred to as the surface mixed layer. This layer is in contact with the wind and air above the ocean. The wind acts as a mixer, moving the water up and down throughout the top layer of the ocean. As a result, all of the water in the surface mixed layer has the same density. Because this water is often in contact with the air, it contains many of the gases required for life, such as oxygen and carbon dioxide.

WORDS TO KNOW

Abyssopelagic zone: The deep ocean that extends from 13,000 feet (4,000 meters) below the surface to the seafloor.

Bathypelagic zone: The layer of the ocean below the mesopelagic zone and above the abyssopelagic zone; generally it extends between 3,250 feet (1,000 meters) and 13,000 feet (4,000 meters) below the surface of the ocean.

Bioluminescence: Light that is generated by chemical reactions in bacteria, animals, and plants.

Epipelagic zone: The surface of the ocean where light penetrates; also called the photic zone.

Density: The amount of mass-per-unit volume of a substance. In water, density is primarily determined by the combination of salinity and temperature.

Hadal zone: The layer of the ocean in deep trenches and submarine canyons at depths that can extend down to 35,750 feet (11,000 meters).

Mesopelagic zone: The layer of the ocean below the epipelagic zone and above the bathypelagic zone; generally it extends from about 500 feet (150 meters) to about 3,250 feet (1,000 meters).

Pelagic: Any part of the ocean away from the coast.

Salinity: The concentration of salt dissolved in a liquid.

Upwelling

Phytoplankton need four things to live: water, carbon dioxide, light, and nutrients (substances like nitrogen and phosphorus that are required for growth). In the ocean, getting water is never a problem. There is also a lot of dissolved carbon dioxide in the water. In the epipelagic zone, light is available, so if there are nutrients phytoplankton can grow easily. The problem is that as phytoplankton grow, they use up all the nutrients in the water.

After the nutrients in the epipelagic zone are gone, the phytoplankton and the animals that eat them cannot continue to grow. They will die and sink below the thermocline into the mesopelagic zone. In this part of the ocean, bacteria digest the dead organisms breaking them into the same nutrients required by the phytoplankton in surface waters. Unfortunately, these nutrients are trapped below the thermocline, where there is no light.

In some locations around the world, currents (steady flows of water in a prevailing direction) cause a phenomenon called upwelling. Upwelling brings the water containing nutrients from the deep water up to the epipelagic zone where there is light. In these locations, the combination of nutrients and light results in conditions that are perfect for phytoplankton growth. Important upwellings occur on the western sides of continents and along the equator (the imaginary circle around the Earth halfway between the North and South Poles).

Cannery Row, which was the subject of a famous novel by John Steinbeck (1902–1968), described the enormous sardine fishery off the California coast in the first half of the twentieth century. As a majority of the sardine diet was phytoplankton, this fishery depended directly on the strong upwelling in Monterey Bay.

The epipelagic zone extends about 500 feet (150 meters) into the ocean, although this varies depending on location. Only about 2% of the total volume of the ocean falls in the epipelagic zone.

The thermocline Just below the surface mixed layer is a layer of water where the temperature and density change very quickly. This layer is called the thermocline. In warm tropical waters, the thermocline is very abrupt, while in cold polar waters the thermocline is often rather gentle. Below the thermocline, the temperature is always about 40°F (5°C). The thermocline acts as a density barrier between the surface, where there is light and phytoplankton growth, and the deeper layers of the ocean, where food is often scarce.

Mesopelagic zone

The mesopelagic zone extends from about 500 feet (150 meters) to about 3,250 feet (1,000 meters) below the surface. It is often referred to as the "twilight zone" because it is between

WORDS TO KNOW

Surface mixed layer: The surface of the ocean where wind acts as a mixer, dissolving gases such as oxygen into the water.

Thermocline: The part of the ocean below the epipelagic zone where the temperature changes very quickly with depth.

the epipelagic zone where there is light and the deep ocean where light is absent. The majority of light in this part of the ocean comes from bioluminescence, light that is generated by chemical reactions in bacteria, animals, and plants. Because the epipelagic zone is where phytoplankton grow and where zooplankton and fish feed on phytoplankton, some animals that live in the mesopelagic zone migrate upwards at night to feed. Other animals in the mesopelagic zone rely on food that falls through the thermocline into the mesopelagic zone. Still others have developed special adaptations to prey on the animals that live within the mesopelagic zone. Since food is rather scarce in this zone, predators often have sharp teeth and expandable stomachs to take advantage of anything they encounter, even if it is bigger than they are.

Bathypelagic zone

The bathypelagic zone is the part of the ocean between about 3,250 feet (1,000 meters) and 13,000 feet (4,000 meters) below the surface of the ocean. Light is almost non-existent in this part of the ocean. What little light there is, is generated from bioluminescence from animals and bacteria. The pressure is also extremely great in this part of the ocean. However, marine life still exists here. Fish, jellyfish, mollusks, and crustaceans (aquatic animals having no backbone with jointed legs and a hard shell) all have representatives that live at these extreme depths. Most of these animals are either black or red. Red appears black at these depths, because the only wavelengths of light (wave patterns of light that are perceived by the eye as colors) available are blue light from bioluminescence.

Abyssopelagic zone

The abyssopelagic zone extends from 13,000 feet (4,000 meters) below the surface to the seafloor. In this zone, the waters are nearly freezing and the pressures are immense. Nonetheless, there are some animals that live in this very deep part of the ocean. Squid and jellyfish can be found swimming through the waters in the deep ocean. Often, they have little color but they do have special organs that can produce light. This bioluminescence is used to attract prey and scare away predators. Several kinds of echinoderms (spiny-skinned animals including starfish and sea urchins) are relatively common in the abyssopelagic zone. The basket star has long arms that it waves above the seafloor in order to catch prey. The sea pig is a kind of sea cucumber that digs holes or tunnels in the mud, digesting dead animals and bacteria. Another sea cucumber called the flying cucumber has flaps like wings to fly through the deep ocean. Crustaceans can also be found in the abyssopelagic zone. Sea spiders and isopods (of the shrimp family) are often found in these deep regions.

Very deep trenches (narrow depressions or cracks in the sea floor) can extend down to 35,750 feet (11,000 meters) in some parts of the ocean. Trenches are the deepest parts of the ocean and are classified by some oceanographers as the hadal zone.

Juli Berwald, Ph.D.

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Marine Invertebrates

Invertebrates are animals that do not have a bony internal skeleton, although many do have hard outer coverings that provide structure and protection. More than 90% of all animals are invertebrates and they are classified into at least 33 major groups, or phyla. Nearly every phylum of invertebrates has members that live in the oceans. Six phyla of invertebrates that are commonly found in the oceans are: Porifera (sponges); Cnidaria (corals, jellyfish, and sea anemones); Annelida (segmented worms); Molluska (snails, clams, mussels, scallops, squid, and octopuses); Arthropoda (crabs, shrimp, barnacles, copepods, and euphausids); and Echinodermata (sea stars, sea urchins, and sea cucumbers). Each phyla is divided into smaller groups called classes, which is then split into families and then species.

WORDS TO KNOW

Annelid: A segmented worm such as an earthworm or a polychaete worm.

Arthropod: A member of a group of invertebrates that has jointed appendages and an external skeleton.

Cnidarian: A member of a group of invertebrates that includes corals, jellyfish, and sea anemones; these organisms have stinging cells to capture prey.

Crustacean: A member of a group of arthropods that includes brine shrimp, barnacles, copepods, shrimp, lobsters, crabs, and euphausids.

Echinoderm: A member of the group of invertebrates that includes feather stars, sea stars, brittle stars, sea urchins, and sea cucumbers.

Intertidal: The zone of the seashore between the high tide point and the low tide point.

Invertebrate: An animal that has no internal skeleton or backbone.

Malacostraca: A class of marine invertebrates that includes shrimp, lobsters, crabs, and euphausids.

Mollusk: A member of a group of invertebrates that includes the snails, clams, oysters, scallops, mussels, squid, and octopuses.

Plankton: Animals and plants that drift with the currents.

WORDS TO KNOW

Polychaeta: The largest class of segmented worms that live in the ocean.

Sponge: One of the least complex multicellular animals; a member of the phylum Porifera.

Tentacles: Long appendages on sea organisms that contain suckers or stinging cells and are used to grasp food and move around.

Phylum Porifera

The sponges are the least complex multicellular animals. They generally live attached to a surface and have three basic shapes, encrusting, vase-like, and branching. Sponges live in intertidal (between the tides) zones as well as in the deep ocean. They can be a few inches (centimeters) to 10 feet (3 meters) in diameter. There are nearly 10,000 species of sponges and all but two families are only found in ocean environments.

The general body of a sponge is a central cavity surrounded by a fleshy body riddled with holes. The cells lining these holes pump water into the central cavity. As the water moves through their bodies, the sponge absorbs nutrients, and filters out particles from the water as their food. The name Porifera means "hole bearer," reflecting the many holes in the animals' bodies.

Phylum Cnidaria

The phylum Cnidaria includes jellyfish, sea anemones, and corals. The word Cnidaria comes from the root word *knide,* which means "nettle." It refers to the special stinging cells that the animals in this group have for protection and predation (hunting an animal for food). These cells contain coiled threads that are fired at predators and prey. The threads may contain substances that paralyze or sticky substances that entangle their target.

Cnidarians have two body plans: polyp and medusa. Corals and sea anemones are typical polyps. They are jar-shaped animals with a mouth at the opening of the jar. Tentacles rim the mouth and are used to pull food into the stomach, which is located on the inside of the jar. Sea anemones have a basal disc (tooth-like structure), which is located where the bottom of the jar is, and it is used to burrow (dig a tunnel or hole) into the sand or rocks. Corals have a skeleton made of the mineral calcium carbonate, which cements the individual coral polyps together into a colony (group). Jellyfish have a medusa shape, and this can be visualized as a polyp turned upside-down so that it looks like a bell. Jellyfish swim by contracting their bodies and forcing water out of the bell. They have long tentacles (appendages) surrounding their mouths that are used to capture prey.

Phylum Annelida

The phylum Annelida includes worms that are segmented, meaning that the body is made up of sections. Each body section may have a specialized purpose, such as reproduction, locomotion, or sensing the environment. These segments are apparent on the outside of the worm's body and make it look ringed. The word Annelida comes from the word *annelus,* meaning "ringed." The most familiar member of Annelida is the earthworm, which is not a marine species.

The class Polychaeta (meaning "many-footed") is the largest class of Annelida, with about 10,000 species, most of which are marine (of the ocean). Almost all of them have paired appendages on their segments that can be used for swimming, burrowing, or walking. Polychaetes often have very well developed heads with a variety of sensory organs that detect prey by touch, vision, and smell. They range in appearance from very colorful to very plain-looking. Some swim through the water, others crawl on the sand or rocks, and others live cemented to the seafloor, building and living in tube-like structures.

A moon jellyfish, a marine invertebrate, approaches a diver off the Florida Keys. *© Stephen Frink/Corbis. Reproduced by permission.*

Phylum Molluska

The mollusks are an extremely large phylum with over one hundred thousand species, most of which are marine. Most mollusks have a head, a foot, and a body that is covered by a shell-like covering called a mantle. The three most common classes of mollusks are the snails; the clams, oysters, scallops, and mussels; and the squid and octopuses.

The gastropods are the largest class of mollusks with over eighty thousand species. They include snails, slugs, abalone, and limpets. Most gastropods crawl along the seafloor among rocks, grazing on algae (tiny rootless plants that grow in sunlit waters). Some, however, hunt for their food among plankton, which are organisms that drift through the ocean. Other gastropods filter water for food particles. The majority of gastropods live in coiled shells, which provides protection from predators and protection from the force of waves. The shells are also used to protect animals that live in the areas between low and high tides from becoming too dry.

The bivalves, meaning "two doors," are mollusks that have two shells like clams, scallops, mussels, and oysters. These animals generally live in sediments (sand, gravel, and silt) on the bottom of the ocean and gather food by filtering particles out of the water. Many clams are able to burrow into sand or clay. Scallops can swim by forcing water through their shells. Oysters tend to cement themselves to hard surfaces. Mussels produce tough strings called byssal threads that attach their shells to surfaces in wave-swept areas.

The most complex of the Mollusca phylum are the squid, octopuses, nautiluses, and cuttle fish. Each of these animals has a head that is surrounded by tentacles. They swim through the water using propulsion from their tentacles, much like swimmers kick their legs underwater, and creep along the bottom of the ocean using their tentacles as legs. Cuttle fish and squid have a shell like other mollusks, but it has been internalized. In octopi, the shell is completely absent. The members of this class have excellent eyesight and are considered intelligent.

Phylum Arthropoda

Arthropods are the most numerous invertebrate phylum with over one million species identified. Some scientists expect that there may be as many as ten million arthropods on Earth. All arthropods have a strong external skeleton that protects them from predation and supports their body structures. They have a type of muscle called a striated muscle that allows them to move quickly. They also have legs, antennae, and other appendages that are jointed.

The phylum Arthropoda has three major divisions or subphyla. The subphylum Crustacea includes about thirty thousand different species, most of which live in the ocean. Crustaceans include many different types of marine animals that are divided into several classes. Brine shrimp, which are important fish food and live in very salty water, belong to the class Branchiopoda. The class Maxillopoda includes barnacles and copepods. Barnacles are specialized crustaceans that spend the adult part of their life cemented head-down on hard surfaces like rocks, piers, the bottoms of ships, and even the undersides of whales. Their legs have developed into featherlike appendages that they use to generate water currents to bring food particles into their mouth. Copepods are small shrimp-like animals that are extremely important to the planktonic food web, the network of plankton that form the base of the food chain in the oceans. They are the most numerous animals in the ocean, sometimes reaching densities of more than a million per cubic yard (meter).

The class Malacostraca includes shrimp, lobsters, crabs, and euphausids. There is an enormous amount of diversity among the members of this class, which includes about twenty-five thousand different species. Some malacostracans spend their lives swimming among plankton, others walk along the ocean floor scavenging for food, while others live in burrows and attack prey that come nearby. Many members of this group live and feed off of fish or even other crustaceans. This class is very important to the economy, both as food for humans and as pets in the aquarium industry.

Phylum Echinodermata

All of the six thousand members of the phylum Echinodermata are marine. The root word *echino* means "spiny" and the root word *derma* means "skin." The name Echinodermata refers to the bony structures called ossicles found in the skin of these animals. Echinoderms do not have well developed sensory organs or brains. They all have a water vascular system that is used to circulate nutrients and gasses through their bodies. All echinoderms share the same general appearance, which is based on five similar sections that radiate out from a central point.

There are five classes of echinoderms: feather stars, sea stars, brittle stars (sea stars), sea urchins, and sea cucumbers. Brittle stars are fairly uncommon. There are about six hundred species of brittle stars, living mostly in shallow waters.

Sea stars (commonly known as starfish) use their water vascular system to operate suction cups located on the bottoms of their legs. These suction cups are called tube feet and they are used both for predation and for gas exchange. Sea stars eat by gripping both shells of a clam or mussel with its tube and pulling the prey open. Then it inverts its stomach inside the shells and digests the victim.

Ophiuroids usually look like a small disc surrounded by five long worm-like arms. They are called brittle stars because when they are attacked, they will simply detach the arm that has been the target. Later, the ophiuroid will regenerate its arm.

Sea urchins are usually pin cushion-shaped and covered with sharp spines. These spines are used for locomotion as well as for defense. Between the spines, sea urchins have special appendages called pedicellariae that look like tiny claws. These are used for capturing prey and for cleaning. The mouth of the sea urchin is on its underside and is composed of five tooth-like plates.

WORDS TO KNOW

Baleen: Bristly plates that hang from the upper jaws of baleen whales; acts like a sieve for the microscopic animals during feeding.

Cetacean: A member of the group of marine mammals that includes whales, dolphins, and porpoises.

Echolocation: The ability of dolphins, bats, and some other animals to detect objects and prey by emitting sound waves that bounce off objects and return to the animal's ears or other sensory organ.

Mammal: A vertebrate that nurses its young with milk, breathes air, has hair at some point in its life, and is warm-blooded.

Pinniped: A member of the group of marine mammals that includes seals, sea lions, fur seals, and walruses.

Vertebrate: An animal that has an internal skeleton including a backbone.

Sea cucumbers live on the sea floor and look like cucumbers with five soft ridges. Many live on coral reefs and are extremely colorful. Sea cucumbers feed by extruding feathery appendages that can capture prey that swim too close. When attacked, many sea cucumbers will suck in water and then use the water pressure to eject their internal organs, including their digestive and respiratory systems. The predator becomes confused among all the tissues in the water and may even become entrapped in some of the sticky material. After such an attack, a sea cucumber will regenerate its internal organs over a period of several weeks.

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Marine Mammals

Mammals are vertebrates (animals with a backbone) that share characteristics of nursing their young with milk, breathing air, having hair at some point in their lives, and being warm-blooded. Marine mammals are the species of mammals that depend on the oceans for all or most of their lives. There are about 115 different species of marine mammals. Marine mammals vary from the small sea otter to the giant blue whale.

Some of them live in groups, like dolphins, while others are solitary, like polar bears. All marine mammals share four characteristics:

- They have a streamlined body shape that makes them excellent swimmers.
- They maintain heat in their bodies with layers of fat called blubber.
- They have respiratory (breathing) systems that allow them to stay underwater for long periods of time.
- They have excretory (waste) systems that allow them to survive without drinking freshwater. Instead they obtain the water they need from the food they eat.

Marine mammals belong to three groups called orders. An order is a classification of a group of organisms, which eventually splits into species. Marine mammals are in the orders Cetecea, Carnivora, and Sirenia.

Marine Mammals in the Military

Marine mammals have been used by the U.S. Navy for military purposes since the late 1950s. Modern day programs use Atlantic bottlenose dolphins, Pacific white-sided dolphins, and California sea lions, and training has also been conducted with beluga whales, orcas, and pilot whales. The Advanced Marine Biological Systems (AMBS) program, which supports military marine mammal programs, is located in Point Loma, California.

Dolphins can swim very fast and can maintain those speeds for extremely long periods of time. Also, dolphins use echolocation (sound waves) to detect prey and predators. In fact, dolphin echolocation is more sensitive than any equipment that has been developed by humans. Dolphins are particularly good at finding lost equipment on the seafloor and for locating enemy mines and torpedoes.

Sea lions have an excellent sense of hearing that allows them to detect the source of a noise, and they have vision that is very sensitive in low light. These skills make these marine mammals extremely well suited for military operations involving search and rescue.

Order Cetacea

There are about seventy-seven species of cetaceans, which include whales, dolphins, and porpoises. All of these animals live their entire lives in the water. Cetaceans probably evolved from the hoofed mammals that were similar to horses and sheep. Their front legs became fins that are used primarily for steering, and their hind legs became extremely small flippers or flukes (tail fins) so as to streamline the animals for swimming. Cetaceans swim by moving their strong fluke up and down. They are grouped into two categories or suborders: Odontoceti, the toothed whales, and Mysteceti, the baleen whales.

Suborder Odontoceti The toothed whales account for about 90% of all cetaceans, including dolphins and porpoises as well as the orca (killer whale) and the sperm whale. Toothed whales hunt for prey, which they capture with their teeth. They also have one external hole called a blowhole for breathing. The toothed whales have a large brain for their size and are consid-

A dolphin used by a multinational military team in the Arabian Gulf jumps for its handler before resuming its search for mines and other obstructions to shipping. *© Reuters/Corbis. Reproduced by permission.*

ered to be some of the most intelligent animals. They hunt using sophisticated echolocation, which is the method of detecting objects by listening to the reflected sounds that it calls out.

Suborder Mysteceti The baleen whales have no teeth. Instead, they have bristly plates called baleen, which hangs like a curtain from their upper jaws. Baleen is made from a protein similar to that which makes up human fingernails. When it is eating, the baleen whale sucks in huge amounts of water and then forces the water out through its baleen, which acts like a sieve. These whales diet primarily on tiny animal plankton, animals that drift through oceans. Microscopic plankton are concentrated behind the baleen and then swallowed. Even though baleen whales feed on some of the smallest animals in the world, baleen whales are some of the largest animals in the world. The blue whale, the fin whale, and the gray whale all weigh more than 2 tons (9 metric tons). Baleen whales are also distinguished from toothed whales because they have two external blowholes instead of one.

Order Carnivora

The Carnivora include animals that prey on each other (meat-eaters) like dogs, cats, bears, and weasels. There are two suborders of carnivores that have marine representatives: the pinnipeds and the fissipeds.

Suborder Pinnipedia Pinnipeds include seals, sea lions, fur seals and walruses. They all have flippers that can be used to move around on land as well as on water. Although they swim much more efficiently than they walk on land, they do give birth to their young on land.

Seals account for nearly 90% of all pinnipeds. There are nineteen species that live in all of the oceans and even in a few lakes. Most seal species live near Antarctica and in the Arctic Circle. Seals do not have an external ear, although they can hear very well. They propel themselves with their rear flippers and use their front flippers for steering.

Sea lions and fur seals do have small external ears. Their hind legs are more flexible than those of seals, so they can move around better on land. They propel themselves with their front flippers when swimming.

Keiko the Whale

Keiko was an orca, or killer whale, that was featured in the 1993 Disney movie, *Free Willy.* Keiko inspired many people, both adults and children, to become aware of marine mammals and their incredible behaviors and skills. Keiko also instigated a large educational movement on the importance of marine mammals to the environment.

Keiko was born in the Atlantic Ocean near Iceland and captured when he was about two years old. After several transfers, Keiko was sold to an amusement park in Mexico City, Mexico, where he lived in a small tank. Keiko's health suffered; he was underweight and had many sores on his skin. The success of the movie prompted the movie studio and several charitable donors to buy Keiko from the aquarium in Mexico and to train Keiko for reintroduction into the wild.

In 1994, Keiko was moved to the Oregon Coast Aquarium in Newport, Oregon, where he was treated medically and taught learning skills that he would need to behave like a wild orca. Within a year, he gained nearly 1,000 pounds (2,200 kilograms); his skin sores healed and he learned to eat fresh fish.

After four years in Oregon, Keiko was transferred back to Iceland where he was kept in a pen in Klettvik Bay. Keiko was then trained to compete with birds and other fish for prey. He was fitted with a tracking device so that he could swim away from the pen and into the bay, while still remaining in contact with his caregivers. Eventually Keiko interacted with wild whales and spent days at a time in the open ocean.

In 2002, Keiko swam across the North Atlantic Ocean, covering a distance of 1,000 miles (1,600 kilometers) to the coast of Norway. The trip took nearly two months and Keiko arrived in excellent health. Keiko is considered the first whale to ever be successfully reintroduced into the wild. Keiko died on December 12, 2003, at the age of 27. He was the second oldest male orca to have been in captivity. (Wild orcas live for an average of 35 years.)

Walruses are the largest of the pinnipeds. They do not have an external ear, but they can use their rear flippers for moving on land. The canine teeth (pointed, in the front) of walruses are enlarged into tusks. Walruses swim along the bottom of the ocean using their tusks like runners as they look for clams to eat.

Suborder Fissipedia The suborder Fissipedia includes cats, dogs, raccoons, and bears, as well as two marine mammals: sea otters and polar bears. Sea otters are about 4 feet (1.2 meters) long, the smallest of the marine mammals. Their favorite food is sea urchins, which they eat by lying on their back and smashing them on a stone that is balanced on their chests. Polar bears wander long distances across sheets of floating ice in the Arctic hunting for seals and whales. They can swim between patches of ice using their powerful forepaws like oars.

Keiko the killer whale swims in a tank at the Oregon Coast Aquarium. © *Kevin Schafer/Corbis. Reproduced by permission.*

Order Sirenia

The sirenians, also called sea cows, evolved from the hoofed land mammals, like the cetaceans. The Sirenia include the manatees, which are large plant-eating marine mammals, and the dugongs (commonly known as sea cows). They are the only plant-eating marine mammals, eating sea grasses and algae (tiny rootless plants that grow in sunlit waters) in warm waters. They grow to be quite large, up to 15 feet (4.5 meters) and weigh 1,500 pounds (680 kilograms).

Endangered Marine Mammals

According to the Endangered Species Act, an animal that could become extinct in all or part of its range is endangered. An animal's range is the entire area where it lives. Of the 115 species of marine mammals, 22 were considered endangered as of 2004, including the blue whale, the gray whale, the finback whale, the Hawaiian monk seal, the stellar sea lion, the marine sea otter, and all four species of dugongs and manatees. Much of the threat is due to human activity. People hunt these animals for their pelts, blubber, and meat, and destroy their habitat from overfishing and mining.

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Plankton

Plankton is a general term that includes plants, animals, and bacteria that drift through lakes and the oceans. Plankton are the foundation for all life in the ocean and produce much of the oxygen that sustains life on Earth. Plankton represents a diverse and large group of organisms. Often, the only factor that the nearly ten thousand different species of plankton have in common is their poor swimming ability. Rather than control where they are moving, like fish, whales, and turtles, plankton simply float wherever the water currents take them. In fact, the word plankton is derived from the Greek word *planktos,* meaning "to wander."

Studying and classifying plankton

Biologists identify and count plankton found in water samples. Several different methods are used to collect plankton from water samples, the most common of which includes the use of plankton nets. Most plankton nets are made of nylon or synthetic material that is produced so that the size of the holes between the fibers is uniform. The most common shape for a plankton net is cone-shaped, and the large end of the cone is attached to a metal net ring. The diameter of the net ring is usually 39 inches (1 meter). The small end of the cone is fitted with a plastic bottle, called a net bucket. The net is pulled slowly behind a boat for a specific distance and plankton larger than the holes in the net are trapped in the net bucket. The net is then reeled into the boat and the plankton trapped in the net bucket are removed for study.

Once the plankton have been removed from the net bucket, scientists identify and count the different species of animals and plants. Once the number of a certain type of plankton found in the net bucket has been counted, biologists calculate the concentration of that organism. The volume of water sampled can be calculated by multiplying the distance the net was towed by the area spanned, by the net ring. The concentration of different types of plankton gives biologists information about the water quality and ecology (study of the relationships between organisms and their environment). Biologists also use some of the larger and sturdier plankton removed from the net bucket for experiments involving nutrition, reproduction, and different processes in the human body.

Many plankton are extremely small and pass through even the smallest holes in plankton nets. In order to study these plankton, biologists filter a specified amount of sample water through membranes (tissue) that have very small holes. The water will pass through the membranes, but any plankton larger than the holes in the membranes will be concentrated on top. Researchers can then attach the membranes to slides and view them under a microscope. Special dyes are often used to stain

WORDS TO KNOW

Bacterioplankton: Plankton composed of bacteria, often serving as the basis of the aquatic food chain.

Bioluminescence: A chemical reaction within an organism that produces light; high concentrations of dinoflagellate plankton can cause bioluminescence in the ocean, often seen at night in waves breaking upon a ship or on the shore.

Diatoms: Single-celled phytoplankton that produce a thin shell made of silica (glass).

Dinoflagellates: Single-celled phytoplankton that move by propelling whip-like appendages called flagella.

Food chain: Hierarchy of food sources (organisms) that interconnect to support different forms of life, where each member is eaten in turn by another.

Holoplankton: Plankton that spend their entire life cycle floating and drifting among the currents.

Macroplankton: Plankton large enough to be seen by the naked eye, including larval forms of jellyfish and some species of crustaceans.

Meroplankton: Plankton that spend only the initial part of their life cycle as plankton, such as shrimp, crabs, lobsters, and jellyfish.

Phytoplankton: Plankton composed of plants and plant-like bacteria, such as algae.

Zooplankton: Plankton composed of animals, such as young crabs, shrimp, or other crustaceans.

the plankton in order to see them more clearly. In other cases, the membranes with the plankton on them are ground up and are analyzed chemically, which helps researchers determine the types of plankton in the water.

Because there are so many different types of plankton, counting and identifying them is time-consuming and often difficult. Instead, biologists often classify plankton into broad groups that simplify the process, but still provide important information about the ecology of the water sample. Three criteria often used for plankton classification are size, cell structure, and life history.

Size of plankton There are six major size categories of plankton. They range in size from plankton far too tiny to be seen with the naked eye to organisms that are many feet (meters) long.

- Net plankton: These plankton include species that are large enough to be caught in plankton nets.
- Macroplankton: Plankton larger than 0.79 inches (more than 20 millimeters) are called macroplankton. *Macro* is the prefix meaning "large." Macroplankton include the larval

Scientists store a jar of plankton for later laboratory study. © *Ted Spiegel/Corbis. Reproduced by permission.*

(immature worm-like stage) forms of many fish, some marine worms, many different types of crustaceans (water animals with an outside skeleton, including shrimp, crabs, lobsters) and jellyfish that can have tentacles stretching 25 feet (8 meters). Some plants are also classified as macroplankton, such as the giant seaweed *Sargassum*.

- Mesoplankton: Plankton between the sizes of 0.79 to 0.0079 inches (20 to 0.2 millimeters) are called mesoplankton. The prefix *meso* means "medium." Examples of mesoplankton are shrimp-like creatures called euphausids and many types of larval fish.
- Microplankton: These plankton range between 0.0079 to 0.000079 of an inch (between 0.2 and 0.02 millimeters. The prefix *micro* means "small."
- Nannoplankton: Plankton between 79 ten-thousandths to 79 millionths of an inch (between 0.02 to 0.002 millimeter) are called nannoplankton. These plankton are so small they must be concentrated on filters in order to be identified. The prefix *nanno* means "very small." These plankton include many different types of protozoans (a type of one-celled animal), single-celled plants, and the larvae of crabs, sea urchins, and mollusks.
- Picoplankton: The smallest group of plankton is the picoplankton, which are less than 79 millionths of an inch (2 thousandths of a millimeter or 0.0002 millimeters) wide. Picoplankton are the smallest and most numerous plankton in the ocean. The prefix *pico* means "extremely small." Picoplankton include bacteria that ingest organisms for food organisms, as well as a type of bacteria that can gather energy from the Sun as do plants. Picoplankton also include many different species of single-celled protozoans and single-celled plants.

Cell structure of plankton. Plankton are classified into three major groups according to cell type: phytoplankton, zooplankton, and bacterioplankton.

Phytoplankton: Phytoplankton are plants and oxygen-like bacteria. The prefix *phyto* means "plant." Most phytoplankton are single-celled organisms, although there are some phytoplankton that form colonies (groups) and others that are multicellular, such as seaweed. In the open oceans, about three-fourths of phytoplankton are nannoplankton. In coastal waters and lakes, phytoplankton tend to be larger, in the microplankton size range.

Diatoms are the most numerous group of phytoplankton. Diatoms are single-celled plants that can be shaped like rods, spools of thread, or pillboxes (round boxes with a top and bottom of equal height). They secrete two shells made of silicon, the same substance that makes up glass. The plant cell lives inside the silicon shells and produces threads that protrude through perforations in the shells. In some species, the threads join with threads on other diatoms and form long chains. Diatoms are usually found in the surface waters and when conditions are right, they can reach high concentrations that can make the water appear green.

After diatoms, dinoflagellates are the next most common group of phytoplankton. Dinoflagellates come in many different shapes, but commonly look like a chocolate candy kiss placed bottom to bottom with another candy kiss that has two peaks instead of one. Most have two flagella (whip-like appendages) that they use like propellers to spin through the water. Some are covered with protective plates composed of cellulose, the material that makes up the woody part of trees. A few species of dinoflagellates contain chemicals that poison fish and, occasionally, people. Other dinoflagellates contain pigments that make the ocean appear red.

Zooplankton: Zooplankton are animal plankton that wander in the water currents. Because they are poor swimmers, most zooplankton have special feeding structures that allow them to capture food that they bump into as they drift. These structures come in all forms, from sticky hairs to nets made out of mucous, to brush-like appendages that sweep food particles toward the mouth. Most zooplankton diet on phytoplankton.

The most common zooplankton in the ocean are the crustaceans, which include the crabs, shrimp, and lobsters, and account for about 70% of all zooplankton. In particular, a small shrimp-like animal called the copepod is the most numerous

Red Tides

Red tides are actually not tides at all, but rather the common name for patches of ocean or lake water that are given their color by a type of reddish-brown phytoplankton called a dinoflagellate. Under certain environmental conditions (such as after a winter rainstorm), these single-celled plants can quickly grow to extremely high concentrations. When dinoflagellates occur in these dense "blooms," they actually make the water appear red. Some of these blooms become so large they can be observed from satellites in space. One of the common dinoflagellates that cause red tides in the waters off of California is called *Gymnodinium breve.* This species can also produce sparks of light called bioluminescence. During a red tide, these phytoplankton cause the tops of waves to glow at night.

Most red tides are harmless, but some do have negative impacts. As phytoplankton grow very quickly, they consume most of the nutrients in the water. After the nutrients are gone, the phytoplankton cells begin to die and bacteria grow on them. These bacteria consume oxygen as they break down the dead plant cells. This can cause the water to become depleted in oxygen. When this occurs, fish and other invertebrates that need oxygen die. As a result, red tides are often associated with large fish kills. Some dinoflagellates contain harmful chemicals that are poisonous to fish and humans who consume the fish. These chemicals can cause aches, stomach pains, dizziness, and tingling in the fingers.

type of animal in the plankton family. In fact, if all the copepods in the world were divided equally among all the people in the world, each person would receive one billion copepods. Another common zooplankton is the shrimp-like crustacean called the euphausid. Euphausids, also called krill, are slightly bigger than copepods, around 2 inches (5 centimeters) long. They are so numerous in the waters around Antarctica that the diet of many whales consists entirely of krill. In fresh water, the tiny crustacean Daphnia is the most numerous zooplankton. Daphnia are particularly interesting zooplankton because they can reproduce without mating in the spring and summer using a process called parthenogenesis, where female Daphnia produce exact copies of female offspring.

Other important animal groups found among zooplankton are the jellyfish, the worms, the mollusks (squid and snails), and the echinoderms (sea cucumbers and sea urchins). Some zooplankton are single-celled organisms called protozoans. For example, the foraminifera are a type of amoeba (a one-celled animal) that has a shell with holes through it. Foraminifera produce sticky spines that extend through the holes, where animals that bump into them are captured and eaten.

Bacterioplankton: The smallest type of plankton, bacterioplankton are microscopic single-celled organisms. Along with other forms, they play an important role in the ecology (living organisms and their environment) of aquatic systems. Bacteria are single-celled microscopic organisms. These organisms are numerous. Bacteria digest dead zooplankton and phytoplankton, producing the nutrients and other materials needed for new life to grow.

Life history of plankton Plankton are also classified according to their life history. Most species of bacterioplankton, phytoplankton, and zooplankton spend their entire life floating and drifting with the currents. These plankton are called holoplankton (*holos* is the Greek root meaning "entire").

Other plankton live only the early part of their life as plankton; the adult part of their life is spent in a different part of the ocean or lake. These plants and animals are called meroplankton (*meros* is the Greek root meaning "mixed"). Some examples of meroplankton are sea urchins, sea slugs, lobsters, worms, and some coral reef fish. Some aquatic plants are also meroplankton. Many meroplankton scatter eggs into the plankton, where they are fertilized. The fertilized eggs develop into larvae, which float in the plankton. Just as a caterpillar looks nothing like a butterfly, in general these larvae look nothing like the adults they will eventually become. When the larvae are in the plankton, they eat other plankton or survive off of the yolk that was with them in the egg. Depending on the species, the larvae remain in the plankton for varying periods of time from several days to several months. Afterwards, the larvae settle onto the seafloor or swim away from the plankton and change into their adult form.

Importance of plankton

Plankton are vital to the global climate. Phytoplankton perform photosynthesis, which is a process that uses the energy from sunlight to produce food. In the process of photosynthesis, phytoplankton take in carbon dioxide and produce oxygen. About half of the oxygen on the planet comes from phytoplankton photosynthesis. As humans burn oil and gas to keep their cars moving and their houses warm, carbon dioxide is produced. This carbon dioxide holds heat and is one of the leading causes of global warming. It is estimated that phytoplankton remove three billion tons of carbon dioxide from the atmosphere each year, as much as all the trees on land.

Plankton are also key to the ecology of the ocean. Phytoplankton are the base of the marine food chain. In other words, they are the food for zooplankton, corals, and mollusks. Even some sharks, such as basking sharks and nurse sharks, rely on phytoplankton for their diet. In turn, fish and larger predators eat the zooplankton. In fact, the giant blue whale relies entirely on shrimp-like zooplankton called euphausids for its diet. Humans also eat fish that prey on plankton.

After plankton die, they sink to the bottom of the ocean. Over millions of years, the dead plankton are buried by sediments, and then eventually converted into fossil fuels such as oil and gas.

Juli Berwald, Ph.D.

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Tides

Tides are the alternating rise and fall of bodies of water, relative to land. Each 24-hour period, there are two high tides and two low tides. The arrival times and heights of the tides change every day and follow a pattern over days, months, and seasons. The shape of a coastline, water depth, shape of the seafloor (bathymetry), weather, and other local factors affect the heights and arrival times of tides at specific locations. The daily tides bring ocean nutrients that nourish brackish-water (slightly salty) plants and wildlife that live in tidal wetlands.

Explaining the tides

Humans in maritime (sea-going and coastal) societies have always recognized and measured the daily, monthly, and yearly pattern of water level rise and fall along coastlines. Navigation, construction, and fishing in coastal areas require precise knowledge of the local tides, and tide prediction is an ancient science. The ancient Hawaiian "moon calendar" charts the tides and relates them to fishing and agricultural harvests. John, Abbot of Wallingford, who died in 1213 supposedly authored the oldest European tide chart. One entry predicts the hours of high water at London Bridge ("flod at london brigge") on the Thames

River. The scientific explanations for how the tides work and why they occur are, however, relatively new discoveries. Ancient Chinese and European philosophers theorized that Earth inhaled and exhaled water. Most ancient scientists, including Greek philosopher Aristotle (384–322 B.C.E.), were silent on the subject of tides. (Ancient Egyptians, Greeks, and Romans lived on the Mediterranean Sea, which has relatively insignificant tides.)

Isaac Newton's theory of gravity is the basis for understanding tides. Newton (1642–1727), a seventeenth century English mathematician and physicist, theorized that all objects exert an attractive force, called gravity, on other objects. The strength of the gravitational pull between objects depends on their relative sizes and the distance between them. Earth, a very large object, pulls smaller objects, like people or apples, strongly toward its center. (Newton's theory of gravity was supposedly inspired by his observation of an apple falling from a tree.) Earth's gravitational pull keeps the Moon in orbit around the planet. Newton's ideas were later applied to an explanation of tides by French mathematician Pierre Simon Laplace (1749–1827), and Irish physicist William Thomson (1824–1907), who is also known as Lord Kelvin.

How tides work

The gravitational pull of the Moon and Sun on Earth's oceans, inland seas, and large lakes causes tides. The Moon's pull on the surface of the oceans as Earth spins on its axis causes two high tides and two low tides during each 24-hour day. To visualize the tides, imagine Earth as a ball completely covered with water. Earth's gravity holds the water on the planet's surface. The Moon's gravity pulls a bulge of water toward it. Another force due to the spinning of the Earth and called the centrifugal force also bulges water at the equator in an outward direction, much like a fast-spinning amusement ride pushes your body toward one side of your seat. Centrifugal force causes a second bulge to form on the direct opposite side of Earth to balance the bulge facing the Moon. As Earth rotates on its axis over 24 hours, the bulges remain stationary with respect to the Moon. Every location on Earth experiences the passing of both bulges in the form of two high tides each day. The low water moments between the bulges cause two daily low tides.

The relative positions of the Earth, Moon, and Sun constantly shift. The Moon's monthly circuit around Earth causes the tides to occur slightly later each day. If the Moon were stationary over the spinning Earth, the high tides would be exactly 12

WORDS TO KNOW

Centrifugal force: Force that pulls objects moving in a circle away from the center of the circle.

Gravity: The natural force of attraction between any two bodies. Very large bodies, like Earth, draw objects toward their surfaces. Attraction between two massive bodies, like Earth and the Sun, is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

Neap tide: Lowest tides of the month that occur at the second and fourth quarters of the Moon.

Spring tide: Highest tides of the month that occur at the new and full Moon.

Tidal wave: The swell or crest of surface ocean water created by the tides. Term is also used to refer to an unusual water rise along a coastline as created by a storm or undersea earthquake.

Tsunami: Very large ocean wave created by an undersea earthquake or volcanic eruption.

A low tide strands boats near La Flotte, Ile de Re, France. © *Nik Wheeler/Corbis. Reproduced by permission.*

hours apart, and tides would occur exactly every six hours. As it is, the first high tide of a 24-hour day happens about 50 minutes later than the previous day.

The gravitational pull of the Sun also affects the height of the tides. Solar (sun) tides are much weaker than lunar (moon) tides because the Sun, although much larger than the Moon, is much farther away from Earth. The relative positions of the Earth, Moon, and Sun constantly change during Earth's yearlong trip around the Sun. Very high and very low tides, called spring tides, occur when the Sun and Moon are aligned and pulling at the tidal bulges from the same or exact opposite sides of Earth. Spring tides happen twice a month (about every 15 days) during the new and full moons. The opposite conditions, when high tide is not very high and low tide is not very low, are called neap tides. These happen when the Moon and Sun are at right angles to each other so their gravitational forces cancel one another.

Tides vary around the world

Earth is obviously not a perfect, water-covered sphere. The continents, seafloor, ocean currents and (mass of air surrounding Earth) winds all affect the tidal bulges as they move around Earth each day. Some places, like the Bay of Fundy in Nova Scotia, Canada, and the English Channel between Great Britain and France, experience very large tides. Other places, like the Mediterranean Sea, have barely noticeable tides. Sometimes the shape of an inlet (a narrow body of water between two islands or leading inland), bay, or harbor delays the tides; in the Gulf of Mexico there is only one high and one low tide each day. A large storm like a hurricane can add to the tidal bulge as it approaches the shore. Along many coastlines, strong tides carry salt water and ocean sediment (particles of sand, gravel, and silt) far inland. Many rivers, bays, and estuaries (coastal wetlands) experience tides many miles from the ocean.

Laurie Duncan, Ph.D.

Tides in the Bay of Fundy

The Bay of Fundy in Nova Scotia, Canada, has the highest (and lowest) tides in the world. The difference between high and low water marks can be as much as 45 feet (14 meters). (In most places around the world, water level changes about 3 to 6 feet [1 to 1.9 meters] between high and low tide.) The Minas Basin at the inland end of the Bay of Fundy is completely dry several hours before low tide. Hundreds of thousands of migratory birds and a good number of humans collect shellfish on the exposed tidal flats during low tide. Luckily, birds have wings and humans have tide charts, because neither should be there when the tide comes in. The roar of the incoming tide sounds like a freight train, and the weight of the incoming water actually tilts the edge of the continent.

Although the gravitational pulls of the Sun and Moon ultimately create the tides, the shape and depth of coastal inlets can drastically affect the height of local tides. By coincidence, the Bay of Fundy is exactly the right shape and size for a phenomenon called resonance that magnifies the normal tide by a factor of ten. The time it takes for water to slosh from one end of the Bay of Fundy to the other almost exactly matches the time between high tides in the Atlantic Ocean. When the outgoing "tidal wave" reaches the inlet to the bay, it meets the incoming Atlantic tide and gets another inward push, rather like a child being pushed on a swing. In addition to enjoying the impressive sight of the Bay of Fundy tides, humans use turbines (spinning wheels that convert fluid motion to an electrical current) in the bay to generate electricity.

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Waves

Wind creates waves. As an air current (moving stream of air) moves over an undisturbed water surface, friction between air and water creates a series of waves that move across the surface. The size of the waves depends on the wind speed, the duration of the wind, and the distance over which the wind blows. (The distance of open water surface that the wind blows over is called the fetch.) A week-long tropical storm in the Pacific Ocean might produce waves as tall as three-story houses; a ten-minute gust blowing across a small lake might make waves that are only a few inches tall.

Waves move away from their point or area of origin in widening circles, like ripples moving away from a pebble dropped into a pool. In an ocean basin (the deep ocean floor), waves from many different wind events are moving across the sea surface at any given moment. When sets of waves meet they interact to form new patterns. By the time they reach the coastline, waves have been affected by many wind events.

Ocean waves may appear that the water is moving forward but in actuality the water is moving in a circle as the water molecules lift and fall. (A molecule is the smallest unit of a substance that has the properties of that substance.) Imagine floating in the ocean in a raft. When a wave approaches, you rise and fall as it passes, but you don’t move toward the beach. The same thing happens to the water molecules below you. As a wave arrives, the water particles rise and fall in small circles as the wave passes, but they are not carried forward. The highest point the wave reaches is called the crest. The lowest point of the wave is called the trough. The wavelength is the distance from one crest to the next. The water molecules closest to the surface move in the largest circles, and deeper water moves less. Molecules below a depth known as wave base are undisturbed by a passing wave. Wave base is equal to half the horizontal distance between wave crests, or one-half a wavelength.

Breaking waves

Waves change form when they approach a coastline. When the seafloor is shallower than the wave base, it interferes with the circular motion of the water at the bottom of the wave.

WORDS TO KNOW

Crest: The highest point of a wave.

Headland: Point that extends into the ocean; usually a high rocky point surrounded by sea cliffs.

Longshore current: Near-shore current that runs parallel to a coastline.

Swash: The forward and backward motion of water where waves break upon the shore.

Trough: The lowest point in a wave; occurs between the crests.

Wave base: Water depth at which water is undisturbed by a passing wave. Wave base is at a depth equal to half the horizontal distance between two neighboring wave crests (½ wavelength).

Wave refraction: Wave fronts bending when they approach a coastline at an angle.

Surfing the Perfect Wave

If you want to know about waves, ask a surfer. The conditions that produce perfect surfing waves are rare, and the sport of surfing is also a study of subtle patterns of wind, weather, and waves along coastlines. The classic 1964 surf movie, *Endless Summer,* follows two surfers as they follow summer around the globe—from California, to Africa, Australia, New Zealand, Hawaii, and back to California—in search of the perfect wave. Surfers also rely on their knowledge of waves and coastal hazards to keep them safe.

Here are some useful terms that surfers commonly use:

- Barrel, tube: The barrel, or tube, is the hollow front of a breaking wave. Sometimes the crest of the wave curls all the way down to the water enclosing the surfer in a spinning tube of water. This is a "totally tubular" ride.
- Break: A break is a line of breaking waves. Surfers wait to catch waves just seaward (in the direction of the sea) of the break. A beach break, where waves break on the sandy seafloor in front of a beach, is a good place to learn to surf. Reef breaks, where waves break on offshore reefs or rock shoals, and point breaks around rocky headlands are strictly for experts.
- Lefts, rights, and peaks: A left is a wave that breaks from right to left when viewed from the beach, and right is a wave that breaks from left to right. (This is wave refraction.) Surfers ride lefts to the left and rights to the right. A peak is a wave that breaks almost parallel to the beach and surfers can ride this in either direction.
- Onshore/offshore winds: For surfing, winds blowing onto the shore (onshore breezes) are bad and winds blowing off of the shore (offshore breezes) are good. Wind blowing toward the beach knocks the crests of breaking waves over and they crumble into "foamies." Wind blowing away from the beach stabilizes the curl of the breaking waves and helps create barrels.
- Pipeline: This is the classic Hawaiian surf break. Also called the Banzai Pipeline, this most-photographed break on the north shore of the island of Oahu has huge waves with perfect, massive barrels.
- Rip: This strong, shallow current that can drag swimmers and surfers far out to sea is usually quite narrow and, unlike undertow, will not drag you underwater. If you are caught in a rip current, don't panic.Swim parallel to the beach to escape instead of straight back against the current.

Waves that were broad, gentle swells in the open ocean grow taller and their crests get closer together. Eventually, the wave grows too tall to support itself and it breaks; the wave crest collapses over the front of the waves. Spilling breakers that gradually become more steep and then crumble typically form along shallowly sloping shores. Plunging breakers that grow tall and curl sharply generally pound steep coastlines. Big waves start to break farther from shore than smaller waves because they have deeper wave bases.

A surfer attempts to swim out against an approaching wave. *© David Pu'u/Corbis. Reproduced by permission.*

Water from breaking waves sloshes forward up the beach. It returns in an outgoing current along the seafloor called undertow. The forward and back motion of water in the surf zone (area of rough water next to the land, where ocean waves hit the shore) between the breaking waves and the beach is called swash. Like water in a washing machine, water in a surf zone endlessly cycles between the breakers and the beach. Beaches are subjected to relentless swashing that breaks down all but the most resistant sediments (sand, gravel, or silt). The mineral quartz is particularly strong, and beach sand is often composed of identical quartz grains that waves have rounded into perfect spheres and sorted by size.

Wave refraction

Waves bend when they reach coastlines. It is extremely rare for wind to blow exactly toward a perfectly straight coastline, and waves almost always approach shorelines at an angle. Wave bending or refraction occurs because the end of a wave that reaches shallow water first slows down and breaks before the deeper end. Water moving in the surf zone flows sideways along the beach from the direction of the approaching wave, and gravity pulls the returning water directly downhill. Water and sediment thus move in a zigzag pattern that carries them along the beach. Wave refraction produces longshore currents, which are currents that flow parallel to coastlines in shallow water. If you have ever dropped your towel on the beach and gone for a swim only to discover that you have been carried away from your towel, you have experienced a longshore current.

Wave refraction also brings the eroding power of waves onto headlands, the jagged, rocky, narrow strips of land that extend into the ocean. Longshore currents carry the eroded sediment away from headlands and deposit it in bays. Waves thus, straighten irregular coastlines by wearing down the headlands and filling the bays. A typical arc-shaped bay with headlands at each end has two longshore currents that flow from the headlands toward each other. The shallow, strong, outgoing current that forms at the tip of the bay where they meet is called a rip current. Rip currents also form where large waves pile water between a sand bar (a ridge of sand built up by currents) and a beach. Rip currents, can be dangerous to swimmers because they can form or become strong suddenly.

Waves and longshore currents can also mold sand into strings of barrier islands (a long, narrow island parallel to the mainland) formed from sediment deposits. These islands are often called depositional coastlines. In the Gulf of Mexico, waves have washed sand from the Mississippi River Delta. Longshore currents have deposited the sand in a long streamer of barrier islands along the Louisiana and Texas coastlines. Tidal inlets (inlets maintained by the tidal flow) separate barrier islands from each other and shallow bays called lagoons separate them from the mainland. The barrier island of the United States eastern seaboard, included the Outer Banks of the Carolinas, formed in a similar fashion. Wave patterns and coastline conditions are constantly changing, and coastline features are continuously remolded. The waves from a large hurricane, for example, can completely destroy a barrier island, beach houses and all, and reshape a new one in a matter of days.

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Chapter 3
Fresh Water

Deltas

Deltas are deposits of sediments (particles of sand, gravel, and silt) at the mouths of rivers that flow into the ocean. The mouth of a river is the end where the body of water flows into the sea. Deltas are shaped by interactions of the river's fresh water with the ocean water, tides, and waves. Throughout history, deltas have been important places for human settlement. They are also vital habitats for many animals and plants. In the fifth century B.C.E, Greek naturalist Herodotus coined the name delta to describe the triangular shape of the sediments deposited at the end of the Nile River. The capital Greek letter delta (Δ) resembles a triangle. Most deltas are triangular in shape because rivers deposit larger amounts of sediment where they meet the sea, then fan out into the mouth of the sea to deposit the remaining sediment.

Formation of deltas

As rivers flow through their beds (a channel occupied by a river), the water breaks up rocks and pebbles, which the river then carries with it as it flows. These pieces of rock, sediment, include sand, pebbles, and silt. When the fast-flowing waters of the river reach the ocean, they push against the ocean water. This decreases the speed of the river water, which spreads out along the coastline. As the speed of the river water slows, the sediments that it carries settle to the bottom of the ocean. Over time, the sediments accumulate and form a delta.

In most deltas, the river water is less dense (packed together) than the sea water because it contains less salt. As it flows out into the ocean, it floats on top of the ocean water. This is called

A view of the Mississippi delta from space. © *Corbis. Reproduced by permission.*

WORDS TO KNOW

Aqueduct: Channel or conduit, usually resembling a bridge, that carries water on land or over a valley, from a higher point to a lower one.

Distributary: Channel of water that run through deltas.

Embayment: Indentation in the shoreline that forms a bay.

Hypopycnal flow: River water that floats on top of sea water as it flows out to the ocean; caused by the fact that river water is less dense that salty sea water.

Interdistributary: Land or water that is between distributaries in deltas.

Reclamation: Draining submerged or wetter land to form dry, usable land.

Sediment: Particles of gravel, sand, and silt.

Tidal flats: Flat, barren, muddy areas periodically covered by tidal waters.

hypopycnal flow. (The prefix *hypo* means "under" or "less" and the root word *pycn* means "density.") In places where hypopycnal flow occurs, the salt water that lies under the fresh water is called a salt wedge. The bigger sediments, like gravel and pebbles, are deposited at the tip of the salt wedge (nearest to shore) and the smaller sediments, like sand, are deposited farther out along the salt wedge. The smallest silt grains (fine sediment particles) are transported far offshore with the river water.

The structure of a delta

Paths of flowing water called channels run through the sediments of deltas. These channels are called distributaries and they may be large and relatively permanent or small, transient features. The sides of the channels are made up of piles of sediments called levées. The areas between the distributaries are called interdistributary areas.

Types of deltas

The structure of the distributaries and interdistributary areas depends on where the river empties into the ocean and the

Life in the Ganges Delta

The Ganges and the Brahmaputra Rivers combine as they flow into the Bay of Bengal in the Indian Ocean at Bangladesh. They carry enormous amounts of sediment and the delta that results is the largest in the world. It is estimated that the total amount of sediments entering the delta is one billion tons per year. The area of the delta is about 3,500 square miles (9,000 square kilometers), about the same size as Yellowstone National Park. The source of all this sediment is erosion from the Himalayas and the Tibetian Plateau. The delta is fed by an impressive set of distributaries, but the tides are the major controlling force. Tides may fluctuate by about 7 feet (2 meters) each day.

The area of the delta is called the Sunderbans and it is biologically diverse both in animal and plant life. Many varieties of fish and shellfish are found in the region as well as wild boar, crocodile, sea turtles, deer, and monkeys. A variety of birds migrate through the many islands of the Sunderbans, including storks, heron, egrets, and cormorants. The largest population of Royal Bengal tigers lives in the Sunderbans, where they number about 400. These animals have adapted to the environment, which is often completely flooded, by becoming powerful swimmers. The Sunderbans is home to one of the largest mangrove forests in the world. Mangrove trees are able to live in salt water and their roots are home to many juvenile species of fish and invertebrates.

Many people live in the Sunderbans. Nomadic fishermen train otters to help them catch fish. Woodcutters live in houses built as high as 10 feet (3 meters) above the ground to stay out of the paths of tigers and crocodiles. Honey collectors search for honey during the months of April and May.

Both monsoons (seasonal heavy rains) and cyclones (hurricanes), affect this delta. The people who live in the Sunderbans are impoverished, and even though flood and cyclone warnings are issued, each year thousands of people lose their lives as waters rise. In 1970, a terrible tragedy occurred in the Ganges-Brahmaputra Delta when nearly 500,000 people were killed by the flooding that followed a cyclone. Again in 1991, another flood killed 100,000 people who lived on low-lying islands of the delta.

forces that affect the river water as it flows into the ocean. There are three major types of deltas: river-dominated, tide-dominated, and wave-dominated. Many deltas are formed by a combination of these forces.

River-dominated deltas extend outward from the coast as the river water jets out into the ocean. The sediments deposited by the river tend to form levées that hold channels of water. The aerial view of a river-dominated delta looks like the foot of a bird with several branching channels. River-dominated deltas often have sand bars (long deposits of sand) that are perpendicular to the river. The Mississippi River Delta in Louisiana is an example of a river-dominated delta.

A Bengal tiger leaps around the edges of a Ganges river delta in India. © *Tom Brakefield/Corbis. Reproduced by permission.*

Tide-dominated deltas are deltas where the sediments deposited by a river are redistributed by tides. These deltas have channels cut by the river water as well as channels cut by tidal currents. The result is a shoreline that looks like the fringe on the end of a carpet. Tide-dominated deltas may also have coastal features like sand bars and shoals (a sandbank seen at low tide) oriented parallel to the tidal flow. The Ganges-Brahmaputra Delta in the Bay of Bengal is an example of a tide-dominated delta.

Wave-dominated deltas occur in places where the sediments deposited by the river water are redistributed by waves. Because waves tend to move sediments along the shoreline, the shape of wave-dominated deltas is usually a smooth coastline. If the waves that affect the delta break parallel to the shoreline, the sediments of the delta will tend to be symmetrical on either side of the river. If the waves break at an angle to the shore, the sediments of the delta will tend to accumulate on one side of the delta. The Nile River Delta in Egypt is an example of a delta that is wave-dominated.

Humans and deltas

Deltas play an important role in human life both historically and in present times. The land on deltas is typically very good for agriculture. On the parts of the delta close to the river, the soil is fertilized each year by nutrient-containing floodwaters when the river floods. In addition, by building aqueducts (canals or pipelines used to transport water) from the wetter lands near the river to the dryer lands farther from the water source, it is easy to expand the amount of land available for farming. This practice is called land reclamation. In particular, the fertile Nile delta has supported much of the agriculture in Egypt for thousands of years.

Trade is another reason why humans have lived on deltas. Because of the many distributaries and the access to a major river and the ocean, deltas are regions where goods can be easily exported both inland and overseas. Many of the world's largest ports are in deltas. Also, communication is relatively easy in deltas. Because the land is usually flat, it is easy to build roads. The many waterways make boat travel easy as well.

Life on deltas

The interdistributary areas of deltas can support a variety of different habitats, depending on whether they are closer to the freshwater of the river or the salt water of the ocean. If the interdistributary areas are close to the river and affected by annual floods, they are called floodplains. Other interdistributary areas near the river water may be freshwater marshes, freshwater swamps, or lakes. The interdistributary areas that are closer to the ocean are likely influenced by the tides. They may be tidal flats (flat, barren, muddy areas periodically covered by tidal waters), mangrove (a tree that grows in saltwater) swamps, salt marshes, or marine embayments (an indentation in the shoreline of the sea that forms a bay).

Because deltas have such a broad range of environments, they host a diversity of species. Many different species of plants flourish on deltas, from saltwater trees called mangroves, to sea grasses, swamp sedges, and shrubs. Deltas also serve as nursery grounds for many species of fish and invertebrates (animals without a spine) and many land animals such as snakes and birds. The marine (sea) areas are important habitats for burrowing worms and mollusks, crustaceans (sea animals with hard outer shells) that hunt for food along the seafloor, as well as a variety of different species of fish.

Deltas also serve important environmental roles. They remove harmful chemicals that are deposited in them by river pollution. These chemicals are absorbed by sediments and trapped as new sediments settle on top. Over time, bacteria break down many of these harmful substances and release chemicals that are not dangerous to the health of humans or other animals. Deltas are also known as nutrient recharge zones. When animals and plants die, they are buried in sediments and bacteria digest them. This converts the chemicals in their bodies into the raw materials needed for plants to grow.

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Freshwater Life

The animals and plants that live in freshwater are called aquatic life. The water that they live in is fresh, which means that it is less salty than the ocean. The terrestrial (land) environment that surrounds the freshwater environment has a large impact on the animals and plants that live there. Some factors that influence the freshwater environment include climate, soil composition, and the terrestrial animals and plants in the area.

Just as on land, aquatic plants require carbon dioxide, nutrients (substances such as phosphate and nitrogen needed for growth) and light for photosynthesis, the process where

WORDS TO KNOW

Aquatic: Relating to water.

Epilimnion: The surface of a lake that extends as deep as light penetrates.

Hypolimnion: The deep part of a lake where no light penetrates.

Invertebrate: An animal that does not have a backbone and a spinal cord.

Lentic: Relating to waters that are moving, like in rivers and streams.

Lotic: Relating to waters that are stationary, like in ponds and lakes.

Nutrients: Substances such as phosphate and nitrate needed by organisms in order to grow.

Wetlands: Lands that are covered by water often enough so that it controls the development of the soil.

Zooplankton: Plankton composed of animals that float among the currents.

The rapid currents and small water falls of a stream through the Willamette National Forest provide a home to many species of aquatic life and provide a vital water source to land-based life. *© Steve Terrill/Corbis. Reproduced by permission.*

plants make their food from sunlight, water, and carbon dioxide. Aquatic animals need to breathe in oxygen and consume food. The physical conditions surrounding the body of water or wetland (lands that are covered in water often enough so that it controls the development of the soil) control the availability of these resources. For example, the concentrations of nutrients, oxygen, and carbon dioxide in the water depend on how much air gets into the water and on the chemical composition of the land nearby. The sediments (particles of sand, gravel, and silt) in the water influence how much light reaches the bottom of the lake or river. The temperature of the water affects how quickly animals and plants grow. The characteristics of the bottom of the body of water (sand, mud, rocks) and the speed of the currents (horizontal movement of water) control what kinds of plants and animals can live and reproduce in an area.

In general, freshwater environments are divided into two major categories: lentic waters and lotic waters. Lentic waters are those that are moving, as in rivers and streams. Lotic waters are those that are stationary, as in lakes and ponds. Sometimes, however, rivers and streams flow into lakes and ponds and the two different habitats merge together. Some wetlands may also contain many characteristics of freshwater environments.

A rainbow trout swims against the water current in search of new sources of food. © *Dale C. Spartas/Corbis. Reproduced by permission.*

Life in rivers and streams

Rivers and streams are characterized by several physical features. They are generally comprised of freshwater that flows in one direction. The flow of water is most often from an area of high altitude (like a mountain range) to an area of low altitude (like an ocean). Usually, the water flows quickly initially and slows as it moves downstream. Streams often join rivers, so there is more water at the end of a river than at the beginning. As rivers flow, they erode (wear away) rocks and pick up sediments, making rivers often murkier at the end. Because rivers and streams change so much from their beginnings to their ends, there are many different types of habitats for animals. As a result, the number of animal species that live in rivers and streams is greater than the number of species that live in lakes and ponds.

Plant life in rivers and streams A major challenge facing plants that live in rivers and streams is staying in place, especially in swift currents. Plants have several different techniques to overcome the drag (the pull) of the water. Diatoms are a type of algae. Algae are marine organisms that range in size from microscopic phytoplankton to giant kelp and that contain chlorophyll, the same pigment used by land plants to perform photosynthesis. Diatoms avoid currents by using their small size. They grow in a single layer on the surfaces of rocks. Because of the friction between the rock surface and the water, the water flow slows nearly to a stop within about a tenth of an inch (one-quarter of a centimeter) from the rock's surface. This region is called the boundary layer, and it provides the diatoms with protection from the forces of the current that would otherwise drag them downstream.

Typical large river plants include algae, mosses, and liverworts. These plants overcome the drag of the water by using special adaptations to grip rocks. Large algae often attach themselves to rocks with root-like structures called holdfasts. In addition, plants often anchor themselves in nooks between rocks or where waters pool, to avoid the drag of the river water.

River plants that live within the currents have developed techniques to withstand the forces of the water. These forces would quickly snap any plant with rigid stems or leaves. As a result, plants that live in rivers are very flexible so that they can easily bend and move with the currents.

Diadromous Fish

Diadromous fish are fish that live in two different aquatic habitats. During one part of their lives, they live in freshwater and during another part of their lives they live in saltwater. In order to move from saltwater to freshwater (or freshwater to saltwater), these unique fish must undergo drastic changes that affect the way that their gills collect oxygen from the water. Only about 1% of all fish in the world are diadromous. Two types of diadromous fish are anadromous and catadromous.

Anadromous fish are fish that spend the majority of their lives as saltwater fish and then migrate (move periodically or seasonally) into freshwater to spawn. Many species of salmon, striped bass, sturgeon, and steelhead are all anadromous. In most of these species, the eggs are laid in freshwater and after they hatch the juveniles migrate into the oceans. In most of the salmon species, the adults migrate back to the rivers where they were born, where they spawn and then die. Other anadromous fish migrate back to freshwater to spawn several different times during their lives, returning to the ocean in between spawnings.

Catadromous fish are fish that live most of the their adult lives in freshwater and then migrate to saltwater to spawn. In the United States, the only species of fish that is catadromous is the American eel. It lives in rivers all along the east coast of the United States. When it is ready to spawn it migrates thousands of miles (kilometers) to the Sargasso Sea, near Bermuda. Once it leaves the freshwater, it does not eat, and so after it spawns its energy reserves are used up and it dies.

Animal life in rivers and streams Animals that live in rivers and streams also face the challenge of staying where they are. Many animals have hooks and suckers that they use to attach themselves to rocks. Blackfly larvae that live in streams in the northern United States and Southern Canada have suction cups that they use to stick to rocks in streams. Mayfly larvae have hooks that they use to fasten themselves to the algae growing on rocks.

Other animals have streamlined shapes that minimize drag by presenting little resistance to water. Trout, which are extremely common in oxygen-rich fast-flowing waters, are shaped like torpedoes. Limpets are flattened molluscs that cling to the surfaces of rocks. Their flat shape decreases the currents' drag on them.

Animals that live in streams and rivers have developed interesting ways of gathering food in the fast-flowing waters. Snails, limpets, and caddis fly larvae scrape algae from rocks using special mouthparts. Many different insect larvae, as well as freshwater clams, filter the water for small bits of food. They have specialized mouthparts that look like brushes or combs that they

Sockeye salmon swimming upstream in the Brooks River, Alaska. © *Ralph A. Clevenger/Corbis. Reproduced by permission.*

use to strain the water and extract the edible plankton (animals and plants that float with currents) that float into their reach.

Rivers and streams are homes to a large number of fish. Perch, smallmouth bass, largemouth bass, bullhead, carp, pike, and sunfish prefer the parts of rivers where waters slow. These fish tend to be large, visual predators (animal that hunts another animal for food) that hunt in pools for smaller fish and invertebrates (animals without a backbone). Sculpins and darters prefer the faster moving sections of the river where waters are highly oxygenated. They use the swift current to bring food to them rather than hunting for their prey. Trout are also found in these faster moving parts of the river.

Life in lakes and ponds

Large lakes are often divided into zones. The near-shore area is called the littoral zone. This is the part of the lake that is shallow enough for aquatic plants to grow. The limnetic zone, also called the epilimnion, is the surface water of the lake away from the shore. (The prefix *epi* means "on the surface" and the root word *limn* means "lake.") It extends down as deep as sunlight penetrates. The majority of the plant life in this zone is phytoplankton (microscopic plants that float in currents). The deep part of the lake is called the profundal zone or the hypolimnion. (The prefix *hypo* means "under.") No plant life exists in this zone because of the absence of light. Most of the biological activity is that of bacteria decomposing dead animals and plants.

Seasonal Changes in Lakes Lakes and ponds are greatly influenced by the temperature changes throughout the seasons. The description below is typical for a lake in a temperate (moderate) climate, which experience seasonal temperature changes. Tropical lakes (those in hot and humid areas) will have less dramatic fluctuations in temperatures.

In the summer, the Sun warms the epilimnion. Warmer water is less dense than colder water, so it floats on top of the cooler water in the hypolimnion. The region between the warm surface waters and the cold deeper waters is a transition zone where the water changes temperature very quickly with depth.

This region is called the thermocline. The thermocline acts as a kind of barrier between the surface and the deep waters. In the early summer, the epilimnion is full of life. Phytoplankton can grow quickly because they have plenty of light and nutrients and the water temperature is warm. In turn, zooplankton (animals like crustaceans and small fish that float in the waters) feed on the phytoplankton. These zooplankton are food for larger fish and birds.

As summer progresses, the phytoplankton use up the nutrients in the epilimnion. They begin to die and sink to the bottom of the lake. There, decomposers, like fungi and bacteria, break up the dead phytoplankton and animals and convert them into the nutrients that phytoplankton need to grow. Because the thermocline acts as a barrier between the bottom and the top of the lake, these nutrients are unavailable to the phytoplankton in the epilimnion. Phytoplankton cannot grow in the hypolimnion, where there are nutrients, because there is no light.

In the fall, the air temperature cools, which cools the surface of the lake. Eventually the temperature in the epilimnion becomes the same temperature as that of the hypolimnion. The thermocline disappears and the nutrient-rich waters from the hypolimnion mix with the waters in the surface of the lake. This is called the fall turnover. At this time, the nutrients from the bottom of the lake are mixed throughout the lake. However, because the amount of sunlight decreases in the fall and into the winter, the phytoplankton in the surface cannot grow very quickly.

During the winter, the surface of the lake continues to cool. Freshwater is densest at 39°F (4°C). Ice, with a temperature of 32°F (0°C), is less dense than the deeper waters and so it forms on the surface of the lake. This provides fish and other invertebrates room to live under ice-covered lakes. The ice also acts an blanket-like insulation that helps keep the water underneath from freezing.

In the springtime, the temperatures warm so the ice melts. Eventually the whole lake becomes 39°F (4°C) and so the waters from the bottom mix with the waters from the surface. This is called the spring turnover. As summer begins, the surface waters warm and the thermocline again separates the epilimnion from the hypolimnion. Because of the fall and spring turnovers, the nutrients from the bottom of the lake are available to the phytoplankton in the surface waters. This sets the lake up for the summer's rapid growth of phytoplankton and all the animals that depend on them.

Plant Life in Lakes and Ponds Some of the most plants in lakes and ponds are the smallest. These phytoplankton are usually single-celled plants grouped with the algae. Sometimes they connect themselves together into long strings called colonies. Common phytoplankton in lakes and ponds are diatoms, which have beautiful shells made of silica (the same material that comprises sand); dinoflagellates, which move by snapping their flagella (long whip-like cell extensions that can propel an organism; and cyanobacteria, which are bacteria that perform photosynthesis.

The larger plants in ponds and lakes include large algae and mosses, cattails, reeds, water lilies, bladderworts, willows, and button bush. These plants often grow in mud where the gases that they need to grow—such as oxygen and carbon dioxide—are scarce. Many larger plants have stems that are spongy and they pull gases from the air down into their roots.

Plants on land use their roots to gather water and nutrients, however aquatic plants are surrounded by water, and nutrients are dissolved in the water. Some aquatic plants have given up their roots. For example, duckweed (or water lentil) and watermeal are small pea-sized plants that float on the surface of lakes and ponds in the spring and summer. They absorb nutrients from the water and produce a lot of starches. By the fall, they are so heavy with nutrients that they sink to the bottom of the lake. They live out the winter in the mud at the bottom of the lake, existing on their stores of starch. By spring, they have used up so much of the starch, they are light enough to float again. They pop to the surface just in time to use the strong light of spring and summer for photosynthesis and they begin to use their starch stores once again. Other large plants, like milfoil, water soldier, and water hyacinths also float on the surface of lakes and ponds.

The edges of lakes are often divided into four zones based on the physical environment and the types of plants found there. Beginning farthest from the water, the swamp plant zone contains plants that have roots in the shallow water. At times the water can recede from this zone, leaving the plants roots exposed to the air. Typical plants in the swamp plant zone are rushes and sedges (a type of plant that looks like a stiff grass). The next zone is called the floating-leaf and emergent zone. Here the water never dries up, but the lake is shallow enough that the tops of plants emerge out of the water. A typical plant that lives in this zone is the water lily, which has special gas filled chambers in its leaves that allow it to stay floating on the surface of the water. In the submerged plant zone, plants live entirely underwater. Canadian waterweed and many types of mosses live in this zone. The free-floating plant zone takes up the center of the lake. Here plants without roots, like duckweed and water soldier, float freely on the surface.

Animal life in lakes and ponds Zooplankton float in the epilimnion of lakes and eat phytoplankton and other zooplankton. Usually, these animals are nearly transparent, in order to avoid being seen by their predators. Typical zooplankton in lakes include the water flea, *Daphnia*, which can reproduce without mating. Under normal conditions all of its offspring are female. However, when the animals are stressed, by lack of food for example, they will produce males. This mixes up the gene pool of the population and creates individuals that are likely to withstand environmental changes. Another typical freshwater zooplankton is the rotifer, which has bristles on top of its head that it whirls like propellers in order to move through the water and capture prey.

Stream Shredders

In some rivers, nearly all the plant material comes from leaves and other plant parts that fall into the river from land. As soon as the leaf hits the water, an army of invertebrates is involved in tearing the leaves to pieces. These animals, which include insect larvae and crayfish, are called shredders and they play a key role in stream ecology (relationship between organisms and their environment). The parts of the leaves that the shredders do not eat are consumed by worms and snails, which in turn become food for fish, amphibians, and birds. Breaking the leaves into small pieces is the first step in decomposing the plant material. Bacteria and fungi colonize the plant bits and break them into the nutrients that plants growing in the river need to grow.

Many insects have juvenile stages that are aquatic. Mayflies, caddis flies, mosquitoes, and dragonflies all live for some period underwater in lakes and ponds. They swim among the rocks and plants in the lake bottom for a season or several years. Then they metamorphose (change in appearance) into their adult form and fly away from the water. The bottom of the lake is also home to many different worms, mussels, and crustaceans. These animals feed on the remains of plants and animals that drop to the bottom of the lake from above.

Larger animals live in lakes and ponds. In particular, fish, birds, and amphibians prey on the invertebrates that live in the lakes. Fish such as bluegills eat juvenile insects that swim in the bottom of the lake, while crappies eat zooplankton near the surface. Birds like flycatchers and warblers fly near the surface of lakes, preying on insects that are hatching from their juvenile stage. Frogs also hunt for insects that live near the pond. Still other birds and fish prey on smaller fish. Bass, salmon, osprey, loons, and heron hunt for fish by using their keen eyesight. Beavers and muskrats are mammals that depend on water for their homes. They build dams and lodges, which provide them with protection from predators.

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Groundwater Formation

Groundwater is fresh water in the rock and soil layers beneath Earth's land surface. Some of the precipitation (rain, snow, sleet, and hail) that falls on the land soaks into Earth's surface and becomes groundwater. Water-bearing rock layers called aquifers are saturated (soaked) with groundwater that moves, often very slowly, through small openings and spaces. This groundwater then returns to lakes, streams, and marshes (wet, low-lying land with grassy plants) on the land surface via springs and seeps (small springs or pools where groundwater slowly oozes to the surface).

Groundwater makes up more than one-fifth (22%) of Earth's total fresh water supply, and it plays a number of critical hydrological (water-related), geological and biological roles on the continents. Soil and rock layers in groundwater recharge zones (a entry point where water enters an aquifer) reduce flooding by absorbing excess runoff after heavy rains and spring snowmelts. Aquifers store water through dry seasons and dry weather, and groundwater flow carries water beneath arid (dry) deserts and semi-arid grasslands. Groundwater discharge replenishes streams, lakes, and wetlands on the land surface and is especially important in arid regions that receive limited rainfall. Flowing groundwater interacts with rocks and minerals in aquifers, and carries dissolved rock-building chemicals and biological nutrients. Vibrant communities of plants and animals (ecosystems) live in and around groundwater springs and seeps.

Almost all of the fresh liquid water that is readily available for human use comes from underground. (The bulk of Earth's fresh water is frozen in ice in the North and South Pole regions. Water in streams, rivers, lakes, wetlands, the atmosphere, and within living organisms makes up only a tiny portion of Earth's fresh water.) For thousands of years, humans have used groundwater from springs and shallow wells to fill drinking water reservoirs, and water livestock and crops. Today, human water needs far exceed surface water supplies in many regions, and Earth's rapidly-growing human population relies heavily upon groundwater to meet its ever larger demand for clean, fresh water.

Aquifers: fresh water underground

An aquifer is a body of rock or soil that yields water for human use. Most aquifers are water-saturated layers of rock or loose sediment. With the exception of a few aquifers that have water-filled caves within them, aquifers are not underground lakes or holding tanks, but rather rock "sponges" that hold groundwater in tiny cracks, cavities, and pores (tiny openings in which a liquid can pass) between mineral grains (rocks are made of minerals). The total amount of empty pore space in the

WORDS TO KNOW

Aquifer: Underground rock or sediment layer that yields water for human use.

Artesian flow: Water that rises to the land surface without pumping from confined aquifers.

Discharge zone: Area where groundwater flows out of aquifers on to land surface; some of these zones are in oceans.

Effluent streams and ponds: Bodies of surface water in discharge zones that gain groundwater.

Influent streams and ponds: Bodies of surface water in recharge zones that contribute groundwater.

Karst: Landscapes and geologic layers that have been chemically worn away by acidic rainwater.

Permeability: The ability of fluid to move through a material.

Porosity: Amount of empty space within a rock or soil body.

Recharge zone: Area where water enters groundwater reservoirs by infiltrating through.

Water table: Level below which all pore space is filled with water.

Zone of infiltration: Shallow soil and rock layers with pore space that are at least partially filled with air; water table is the bottom of this zone.

Zone of saturation: Soil and rock layers with pore spaces that are completely filled with fluid; water table is the top of this zone.

Karst and the Edwards Aquifer

The Edwards Aquifer is a groundwater reservoir made of limestone rock that today provides water to nearly 2 million people in 10 central Texas counties. Clear, cool, clean water flows from natural springs and shallow wells along the Balcones Fault zone (a fracture in the crust of the Earth along which rocks on one side have moved relative to those on the other side) that runs through the cities of San Antonio, Austin, and Waco. Diverse communities of plants and animals, including humans, have thrived in the Edwards aquifer discharge zone for tens of thousands of years. Native American tribes including Comanche, Apache, and Tonkawa had been living beside the spring-fed pools of the Edwards, drinking cool water and hunting plentiful game, for more than 12,000 years before the arrival of Spanish explorers and European settlers.

The rock layers that make up the Edwards aquifer are filled with a honeycomb of caves, cavities, and conduits that were created by the chemical reaction between water and limestone. Rainwater dissolves limestone. Each slightly acidic raindrop that falls in the recharge zone of the Edwards aquifer dissolves a little bit of limestone. Over geologic time, the limestone has dissolved has and carved the "plumbing" of the Edwards aquifer. The landscape and geologic features created by the dissolving of the limestone—sinkholes, disappearing and reappearing streams, caves, and caverns—are called karst.

Today, millions of humans share groundwater from the Edwards aquifer with its native biological users. Overuse and pollution are threatening the quantity and quality of groundwater flowing from the Edwards. Although karst aquifers like the Edwards are relatively fast flowing, an average water molecule still spends about 200 years traveling through the aquifer. (Some of the water flowing from Barton Springs in downtown Austin probably entered the aquifer around the time of the American Revolution!) Human activities that prevent water from entering the aquifer, like installing pavement in the recharge zone, or that remove water faster than it enters, like pumping large quantities of water for crops, can lower the water level in the aquifer, and cause springs and wells to go dry. When pollutants like agricultural runoff or industrial chemicals make their way into the groundwater system, they emerge, almost unfiltered, in springs and wells in the discharge zone. Changes in the quality and quantity of the groundwater in discharge pools are threatening a number of species of salamanders, fish, and insects. Environmentalists, developers, and government officials in central Texas are working to find solutions that both protect the Edwards, its ecosystems, and the plentiful high-quality water it supplies the rapidly-growing human population of central Texas.

rock material, called its porosity, determines the amount of groundwater the aquifer can hold. Materials like sand and gravel have high porosity, meaning that they can absorb a high amount of water. Rocks like granite, marble, and limestone have low porosity, and make poor groundwater reservoirs.

Aquifers must have high permeability in addition to high porosity. Permeability is the ability of the rock or other material to allow water to pass through it. The pore space in permeable materials is interconnected throughout the rock or sediment, allowing groundwater to move freely through it. Some high-porosity materials, like mud and clay, have very low permeability. They soak up and hold water, but don't release it easily to wells or other groundwater discharge points, so they are not good aquifer materials. Sandstone, limestone, fractured granite, glacial sediment, loose sand, and gravel are examples of materials that make good aquifers.

Water enters aquifers by seeping into the land surface at entry points called recharge zones and leaves at exit points called discharge zones. (Some aquifers discharge into the ocean.) Influent or " water-losing" streams, ponds, or lakes are bodies of surface water in recharge zones that contribute groundwater from their water supply. Groundwater flows into effluent or "water-gaining" streams and ponds in discharge zones.

For the water level in an aquifer to remain constant, the amount of water entering at recharge zones must equal the amount leaving at discharge zones. (Imagine a bucket punched with holes under a dripping faucet. If water drips in at the same rate that it drips out, the water level stays the same.) If water discharges or is pumped from an aquifer more quickly than it recharges, the groundwater level (water table) will fall. The time an average water molecule spends within an aquifer is called its residence time. Water in some fast-flowing aquifers spends only a few days underground, while other rock layers can hold water for ten thousand years. Average aquifers have residence times of about two hundred years.

The water table and unconfined aquifers Water enters aquifers by moving slowly down through a layer of surface rocks and soil whose pore spaces are partially filled with air (zone of infiltration). The water continues moving downwards until it reaches a level where all the pore spaces are completely filled with water (zone of saturation). The top of the zone of saturation is called the water table. In some wet, lowland regions, southern Florida for example, the water may be only a few feet (meters) below the surface. In others, like the American Southwest, water-saturated rocks may be hundreds of feet below the land surface.

Groundwater reservoirs that have uniform rock or soil properties (porosity and permeability) throughout are called unconfined aquifers. The water table forms the upper surface of an unconfined aquifer. The shape of the water table in an unconfined aquifer mirrors the shape of the land surface, but its slopes are gentler. In temperate (moderate) climates that receive moderate amounts of groundwater-replenishing rainfall, water infiltrates into unconfined aquifers in hilltop recharge zones and discharges into effluent streams and ponds in low areas where the water table intersects the land surface. Water will only rise to the level of the water table in a well, so a pump or bucket is required to extract water from an unconfined aquifer.

Confined aquifers and artesian flow Confined aquifers are pressurized groundwater reservoirs that lie beneath layers of non-permeable rock (granite, shale) or sediment (clay). Groundwater enters a confined aquifer in recharge zones beyond the uphill edges of the confining layer and discharges beyond the downhill edges. Groundwater trapped beneath an impermeable barrier cannot rise to the height of the water table, so pressure builds up in confined aquifers. Artesian wells are wells drilled in confined aquifers where the pressure is great enough to make water flow at the surface.

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Lakes

Lakes are large inland bodies of fresh or saline (salty) water. Lakes form in places where water collects in low areas or behind natural or man-made dams (barriers constructed to contain the flow of water). Some lakes are fed by streams (natural bodies of flowing freshwater), and some form where groundwater (water flowing in rock layers beneath the land surface) discharges onto the land surface. Water leaves lakes by flowing into outlet streams, infiltrating (soaking in) into groundwater reservoirs called aquifers, and by evaporating into the atmosphere (mass of air surrounding Earth). Lakes vary in size from large lakes such as the Great Lakes of North America, to small mountain lakes. Lakes are larger than ponds, which are small bodies of fresh water that are shallow enough for rooted plants to grow. The study of ecology (relationships between living organisms and their environment) in lakes, inland seas, and wetlands is called limnology.

Lakes store only a tiny percentage of Earth's fresh water. They are, however, an extremely important water resource for humans. Freshwater lakes provide water for agricultural irrigation (watering), industrial processes, municipal uses, and residential water supplies. People who live in the continental interiors use lakes for fishing and recreation, and very large lakes have important shipping and transportation routes. Humans also construct artificial lakes, called reservoirs, by building dams across rivers. In addition to providing the benefits of natural lakes, reservoirs also store water for specific communities, control floods, and generate hydroelectricity (electricity generated from water power).

How lakes form and disappear

Earth scientists who study water on the continents (hydrologists and hydrogeologists) see lakes as temporary reservoirs within stream and groundwater systems. All water that falls as precipitation (rain, snow, sleet, hail) on the land surface of continents eventually makes its way to the ocean or evaporates back into the atmosphere. Water collects in lakes because it enters more rapidly than it escapes, but it is never permanently trapped there. As in a tub with a running faucet and an open drain, individual water molecules (smallest unit of water, each containing two hydrogen atoms and one oxygen atom) are constantly entering and escaping. After arriving in a lake, an average water molecule spends about one hundred years before moving to a new reservoir. (The time that an average water

WORDS TO KNOW

Caldera lake: Lake filling a large circular depression left by a volcanic eruption or collapse.

Eutrophication: Proliferation of plant life, especially algae, that results when excess nutrients are added to lake or pond water, which reduces the oxygen content and often causes the death of animals.

Karst: Landscape with caverns, sinkholes, underground streams and springs created by erosion of limestone rock layers by groundwater.

Kettle: Round depression left in glacial sediment after melting of a buried block of ice; form lakes and ponds when filled with water.

Lake overturn: Mixing of lake waters from temperatures causing changes in the water layers' density.

Limnology: Study of the ecology of continental surface waters including lakes, rivers, wetlands and estuaries.

Littoral Zone: Shallow, sunlit zone along lake shores where rooted plants grow.

Playa: Flat areas at the bottom of a desert basins that occasionally fill with water.

Residence time: Time an average water molecule spends in one of the reservoirs of the hydrologic cycle.

Saline lake: Saltwater lake that contains high concentrations of dissolved salts.

Thermocline: Layer when water temperature changes with depth.

molecule spends in a reservoir is called it residence time. Water resides for about two weeks in rivers, forty years in glaciers (slow moving mass of ice), and between two hundred and ten thousand years in groundwater reservoirs.)

To geologists (Earth scientists), lakes are temporary features. Stream-fed lakes within stream systems are destined for destruction. Every stream seeks to create a constant slope, called a graded profile, between where the stream's waters begin and ends by eroding (wearing away) and depositing sediment (particles of sand, silt, and clay) along its course. When a natural or man-made obstruction blocks a stream, such as a river, streams deposit sediment in the lake or reservoir behind the obstruction and erode away in front of it. Eventually, the dam will collapse, and the lake will empty. Lakes that fill depressions and have no outlets fill when the regional climate becomes wetter or when warm periods melt mountain snows and glacial ice. They evaporate away during periods of dry weather and dryer climate. It may take thousands, or even tens of thousands of years, but lakes eventually drain, collapse, or dry up.

Lake layers and overturns

Contrary to their common image as evenly mixed pools of unmoving water, lakes are complex, dynamic bodies of moving surface water. Lake water varies within the lake; its temperature, chemical content, light infiltration, and biological habitats vary from top to bottom and side to side. Furthermore, the vertical layering (stratification), horizontal variations, and circulation patterns within lakes change over time. Waves, currents (a moving mass of water), and even tides affect circulation of water within lakes.

Lakes are thermally stratified (layered according to temperature); they have layers of warm and cool water that are separated by layers where the temperature changes (thermoclines). Like the oceans, many lakes have a thin layer of warm surface water, and a thicker layer of cool deep water that is separated by a thermocline layer. Wind generates currents on lake surfaces and creates some mixing. Unlike the oceans, however, many lakes have seasonal overturns that mix their waters. water is denser than solid water (ice). Water reaches its maximum density at 39°F (4°C). Because of this odd property, the warm less-dense water rises, the cool denser water sinks, ice floats, and lakes overturn. Lakes that are ice-covered for part of the year undergo overturns that partially or completely mix their waters.

Many lakes in temperate (moderate temperatures) regions like the northern United States overturn and mix completely twice a year (dimictic lakes). During the warm summer months, these lakes have a usual temperature profile with warm surface waters, a thermocline, and cool bottom water. In the fall, when the surface water cools down to 39°F (4°C), it becomes denser than the water underneath it and the surface layer sinks to the bottom. The bottom water rises to the surface, and the lake overturns. Over the winter, the bottom water is the warmest, and the frozen surface water is the coldest. (Plants and animals survive the winter on the lake floor in the chilly, but not frozen, bottom water.) In the spring, when the ice melts, and the water warms to 39°F (4°C), it sinks, and the lake overturns again.

Limnologists classify lakes according to the number of mixing events they undergo each year. Lake type classifications have the root term *mictic*, meaning "to mix," and include:

- Oligomictic: Warm, ice-free lakes that rarely mix. They are warmest at the top, and coolest at the bottom. Tropical, oligomictic lakes have warm bottom water and very warm surface water. They rarely overturn because their water does not near 39°F (4°C).
- Meromictic: Warm, ice-free lakes that mix incompletely. These are deep lakes that are warmest at the top, and coolest at the bottom.
- Monomictic/dimictic/polymictic: Lakes with seasonal ice covers that overturn and mix completely once (monomictic), twice (dimictic), or many times per year (polymictic). Lake overturns are the norm in temperate regions, but local conditions affect the timing and number of overturns in specific lakes.
- Amictic: Lakes that never overturn because they are ice-covered throughout the year. These lakes exist near the North and South Poles and atop very high mountains. They have cold bottom water that hovers near 39°F (4°C) and frozen surface water.

Lake chemistry: saline lakes

Many of Earth's largest and most important lakes contain salt water. All surface water contains some dissolved chemicals, called salts. Groundwater, streams, and freshwater lakes all contain the chemical components of rocks and minerals. Humans can drink fresh water because our bodies can use or at least tolerate the types and concentrations of dissolved chemicals it contains. Salt water, on the other hand, has a very high concentration of dissolved salts, and is undrinkable. The Dead Sea, on the border between Israel and Jordan, is Earth's saltiest body of water. It is truly a dead sea because it is too salty to support life.

Saline lakes generally form in arid (dry) regions where surface water evaporates quickly. When water evaporates, the salts stay behind. Over time, the lake water becomes saltier. Some saline lakes, such as the Great Salt Lake, are all that remains of a much larger fresh water lake that has evaporated over time. Others, like the Caspian Sea in central Asia, began as saltwater-filled ocean basins that have since closed.

Saline lakes are often temporary features that fill during periods of wetter climate and then dry up when stream flow or groundwater discharge slows. Playa lakes are flat desert basins that occasionally fill with water. Desert oases (watering holes) form and disappear with such regularity that thirsty travelers think they imagined them. The Great Salt Lake, Caspian Sea, Aral Sea, and Dead Sea are all presently evaporating. Over time, the dissolved chemicals become so concentrated in drying lakes that they bond together and form solid salt crystals. Thick layers of salt cover dry lake beds.

Lake biology

Lakes support rich communities of plants and animals (ecosystems) that have adapted to live within ever-changing conditions on lake beds, within the water column (water running from the surface to the lake floor, often showing differences in temperature, nutrients, etc.), and along lake shores. Lakes, like islands, are often closed systems that only rarely gain new species or individuals from other lakes. Many lakes host groups of rare species that have evolved (changed over time) together in their specific lake. These ecosystems are rich and unique, but fragile. They have little defense against foreign predators or diseases. Human alterations and water pollution have threatened many lake species. Environmental groups and government agencies are presently attempting to protect and revive threatened lake species such as cichlids (rare double-jawed fish) that inhabit the lakes of the Great Rift Valley in east Africa.

Lake organisms live in zones that are determined by the physical structure of their lakes such as the amount of available light, water depth, and distribution of nutrients. Most lake

Dying Lakes: Great Salt Lake and Aral Sea

Utah's Great Salt Lake and the Aral Sea in central Asia are drying up. These large, hypersaline (very salty) bodies of surface water fill terminal basins (large depressions that have no outlets). They filled with water hundreds or even thousands of years ago when the climate was wetter and when rivers supplied them with more water. Today, the amount of water entering the lakes from streams, springs, and rainstorms is much less than the amount of water leaving by evaporation into the atmosphere or infiltration into underground rocks and soils.

Like the oceans, inland lakes and seas are salty because evaporating water leaves behind dissolved minerals. The water that flows into lakes contains the dissolved chemical components of rocks and minerals. When water evaporates into the atmosphere, the salts stay behind. Terminal lakes that only lose water by evaporation and receive very little fresh water from rivers become very salty as minerals accumulate. The waters of the Great Salt Lake and Aral Sea are much saltier than the oceans, and the dry portions of their lakebeds are blanketed with thick layers of salt crystals.

Today, the Great Salt Lake is about three to five times saltier than the ocean and supports only a few species of salt-loving fish and shrimp. Over the long term, the lake is drying, but the amount of water entering the lake from streams varies, so the lake level rises and falls from year to year. The lake fills a broad, very shallow basin, so the positions of its shorelines change drastically as lake levels fluctuate. Industries that depend upon the Great Salt Lake such as salt mines, petroleum fields, and brine shrimp fisheries have learned to adjust to moving shorelines, while recreational facilities such as lakeshore resorts and marinas have not fared as well.

The Aral Sea is a very large saline lake in a terminal basin in the central Asian nations of Kazakhstan and Uzbekistan. Like the Great Salt Lake, it is a remnant of a much larger prehistoric lake that has been shrinking slowly over thousands of years. Unlike the Great Salt Lake, however, the Aral Sea is drying from processes other than long-term climate change.

Forty years ago the Aral Sea was the fourth-largest inland sea in the world. It supported a thriving fishing industry and an economically pros-perous region of several hundred thousand residents who depended on the lake. In 1973, the former Soviet Union diverted the flows of the Amu-Darya and Syr-Darya Rivers to irrigate huge plantations of water-intensive crops in the dry grasslands of central Asia. Without replenishment from these rivers, the Aral Sea shrank to half its original size and lost about 60% of its water.

The rapid retreat of the Aral Sea has caused an environmental and economic disaster in central Asia. Retreating shorelines have hurt ports and marinas. Rising salt concentrations destroyed the lake ecosystem and killed the fish. Dry winds have blown salt and dust particles from the dry lakebed far across the continent where they have polluted soil and water. The local climate has even changed; less rain falls each year, the winters are colder, and the summers are hotter. Blowing salt and droughts have turned once-fertile agricultural lands into unusable desert. Air pollution causes respiratory ailments, and salt in the soil pollutes surface and groundwater. At present, international organizations such as the United Nations and World Bank have abandoned their original plans to revitalize the region by restoring its natural environment and have refocused on meeting the basic needs of the five million people left in peril by the Aral Sea disaster.

Abandoned boats near the shore of the dry Aral sea located in Central Asia in the lowlands of Turan. Many fishermen kept the local fishing industry alive until there was no longer enough water to keep the fishing boats afloat. *© David Turnley/Corbis. Reproduced by permission.*

plants and animals live in shallow, well-lit surface waters called the euphotic zone. Most plants depend on the Sun's energy to produce food by the chemical process of photosynthesis, and they cannot grow in water that is too deep or too cloudy for light to penetrate. Lake animals such as fish need oxygen that plants give off during photosynthesis, so they live mostly in the euphotic zone as well. Plants with roots grow in shallow water along edges of lakes where light reaches the lake floor (littoral zone) and floating plants perform photosynthesis in the open surface waters (limnetic zone). Oxygen-consuming bacteria inhabit the deepest, darkest parts of lakes (benthic zone) where dead plant and animal materials accumulate.

Limnologists also classify lakes by the balance of organisms and nutrients in their waters. Types include lakes that are described as oligotrophic, eutrophic, and mesotrophic.

- Oligotrophic: Nutrient poor lakes that support very few plants and animals. Oligotrophic lakes are typically cool, deep, and have very clear water. Very little organic (relating to or from living organisms) mud accumulates in oligotropic lakes, and they often have sand and gravel beds.
- Eutrophic: Lakes rich in plant nutrients that support abundant plant life in their surface waters. Their water is often clouded by microscopic plants, and their beds covered with thick layers of decaying plant material. Bacteria that live on the organic mud use up oxygen, and eutrophic lakes often have oxygen-poor deep water. Plants and bacteria eventually take over eutrophic lakes. They become oxygen-poor

bogs and marshes where fish cannot live. Some chemicals that humans use, including fertilizers and detergents, cause a process called eutrophication when they run off into lakes, which causes the population of plants to increase to such an extent that eventually oxygen-starved fish die.

- Mesotrophic: Lakes with moderate amounts of nutrients and healthy, balanced communities of plants, animals and bacteria. Mesotrophic lakes receive adequate amounts of fresh water and nutrients, and seasonal overturns allow nutrient-poor and nutrient-rich layers to mix. Mesotrophic lakes are intermediate between crystal-clear, lifeless oligothrophic lakes and cloudy, muddy eutrophic lakes.

Where lakes form: lake basins

Lakes form where water collects in depressions, or basins. Many lakes fill low areas created by plate tectonic movements (tectonic basins) and volcanic activity. (Plate tectonics is the movement of large, rigid pieces of Earth's outer rock shell called the lithosphere.) Retreating glaciers and ice sheets leave behind large basins and small depressions that fill with meltwater. Though flowing streams and rivers generally act to fill in and drain lake basins, other sedimentary processes can create landscape depressions and natural dams that confine water in lakes.

Lakes in tectonic basins Rift valley lakes fill long, linear valleys within rift zones. (Rifts are areas where the continental lithosphere is stretching and beginning to break into pieces. They are the precursors of ocean basins.) A chain of large lakes including Tanganyika, Naiveté, and Malawi follows the Great Rift Valley through eastern Africa. Lake Victoria, the world's second-largest lake, lies between two branches of the rift valley. The Red Sea, Sea of Galilee, Dead Sea, and Gulf of Ababa fill the northern branches of the rift where it crosses the Arabian Peninsula in the Middle East. Russia's Lake Baikal, the world's deepest lake, fills an ancient, inactive rift valley in central Asia.

Lakes also form in places where continents are moving toward each other. The Black Sea, Caspian Sea, and Mediterranean Seas fill a closing ocean basin between Africa and Europe. When continents collide, water fills depressions in the landscape over folded and broken (faulted) rock layers that were caught between the land masses. Slopes that are too steep collapse and block rivers with natural dams. Blocks of uplifted, erosion-resistant rock form bedrock that holds back mountain lakes.

The Glen Canyon Dam of the Colorado River created Lake Powell. © *Nik Wheeler/Corbis. Reproduced by permission.*

Volcanic lakes Volcanoes are mountains that form from eruptions of molten rock (lava) on the land surface. When a volcanic peak collapses into its emptied magma chamber (a pool or room of magna held under tremendous pressure within a volcano prior to a volcanic eruption), it forms a large circular basin called a caldera. (Craters, the small basins near the top of active volcanoes, sometimes also contain small lakes, but most significant volcanic lakes, including inaccurately-named Crater Lake, fill calderas.) Yellowstone Lake in Wyoming and Crater Lake in Oregon are examples of caldera lakes. Volcanic ash, mud, and lava flows also create natural dams in river valleys. A dam of volcanic rock confines Lake Tahoe in a high valley of the Sierra Mountains on the California-Nevada border.

Glacial lakes The thick continental ice sheets that covered northern North America, Europe, and Asia during the Pleistocene ice ages (a division of geologic time that lasted from two million to ten thousand years ago) left behind thousands of lake and ponds when they retreated about twenty thousand years ago. The weight of the ice sheets pushed down on the continents, leaving broad basins that filled with melt water when they retreated. The Great Lakes of North America (Superior, Huron, Michigan, Erie, and Ontario) formed this

The Great Lakes

The Great Lakes of North America: Superior, Michigan, Huron, Erie, and Ontario, together make up the largest system of fresh surface water on Earth, and contain almost 90% of North America's fresh surface water. The lakes fill a broad depression that was created by the massive ice sheet that pressed down on the North American continent during the last Pleistocene ice age. The basin first filled with melted water from ice sheets that retreated thousands of years ago, and is today replenished by rivers, rainfall, and groundwater discharge. Water flows from west to east through the lakes and short connecting rivers. It eventually empties from Lake Ontario into the Atlantic Ocean via the St. Lawrence Seaway. The lakes and their surrounding wetlands, forests, and plains support thriving communities of plants and animals.

Humans have lived in the Great Lakes region for thousands of years. When French fur trappers and traders first explored the banks of Lakes Huron and Superior in the early 1600s, they found economically sufficient, prosperous Native American communities that had lived in the region for centuries. (Chippewa, Huron, Iroquois, Ottawa, Potawatomi, and Sioux are a few of the over 120 native tribes of the Great Lakes region).

Today, 25 million Americans in eight states (Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, and New York) and 8.5 million Canadians in the province of Ontario live in the Great Lakes region. They depend on the lakes for water, transportation, shipping and recreation. Major cities like Chicago, Detroit, and Toronto use lake water for drinking, household use, city supplies, industry, and recreation. Farmers draw water to irrigate fertile agricultural lands in the American and Canadian plains. Ships carry industrial materials and products far inland to the western end of Lake Huron. Man-made channels and locks (chambers the can be filled and drained of water so that boats can be raised or lowered as needed) like the Erie Canal and Soo Locks allow huge ocean-going ships to detour around impassible sections of the system, including Niagara Falls between Lakes Erie and Ontario.

In spite of their immense size and active circulation, the Great Lakes are very sensitive to environmental threats from human activities. Water moving through the Great Lakes system does little to remove or dilute substances such as the water that flows from agricultural lands, mining waste, industrial chemicals, acid rain and sewage. Pollutants tend to collect in the lakes where they threaten fragile natural ecosystems as well as the quality of the human water supply.

Human industry, agriculture, and urbanization in the first half of the twentieth century severely damaged the Great Lakes. By June 1969, the Cuyahoga River that connects Lakes Erie and Ontario had become so polluted with petroleum and industrial chemicals that it caught on fire near Cleveland, Ohio. This event and others like it eventually led to regulations such as the Clean Water Act and Great Lakes Water Quality Act in the 1970s. Today, government regulations, clean-up projects, and scientifically-guided water management by U.S. and Canadian groups have successfully restored the Great Lakes to a semblance of environmental health, though some problems remain to be solved.

way. Hundreds of lakes, such as the Winnipeg, Athabasca, Great Slave, and Great Bear cover the central and eastern provinces and territories of Canada that are still rebounding from their heavy ice load.

Advancing glaciers also pile tall ridges of sediment, called moraines, at their toes (the end of extensions of glaciers along the ground). When glaciers retreat, moraines hold back meltwater. Small lakes and ponds also form in glacial depressions called kettles that form when blocks of ice buried in glacial sediment melt. Melting mountain glaciers feed many mountain lakes and glacial sediment traps streams and meltwater.

Groundwater discharge lakes Water moving through pore spaces in rock and soil layers discharges on the land surface in places where the water table (level below which pore spaces are saturated with water) intersects the land surface. In regions with wet climates, the water table is near the land surface and ground water discharges in low spots. Groundwater chemically erodes limestone and other rocks and creates caves, cavities, sink holes, and collapse basins called karst features. Florida's many lakes, including Lake Okeechobee, are groundwater-filled karst features.

Laurie Duncan, Ph.D.

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Ponds

A pond is a depression in the ground that is filled with water that remains year round. Ponds range in size from the artificial backyard projects about the size of a bathtub to bodies of water that are about the size of a football field. Ponds support a variety of animal and plant life, and are also used as recreational sites by people.

The difference between a pond and a lake involves size and water depth. A lake is big enough to have at least one beach (sand or rock that slopes down to the water) and contains enough water to generate waves from the wind that blows across the surface of the water. In contrast, a pond is usually too small for waves of any size to form. At the center of a lake, the water can reach depths of many hundreds, even thousands of feet (meters). A pond, however, is a shallow and still body of water where sunlight can usually reach down to the bottom.

How ponds form

Natural ponds form in shallow depressions where rainwater (including runoff from nearby higher areas) collects. Water from an underground source such as an underground spring can also collect into a pond.

Ponds that people enjoy in their backyard are often artificial, created by preparing the hole and adding water and plants to create a backyard oasis. These ponds can provide relaxation and a habitat for attracting insects, birds, and amphibians (such as frogs and salamanders), even in backyards located in a bustling city.

Other artificial ponds are workhorses. One example is a sewage treatment pond. This type of pond keeps the sewage in a place where the growth of microorganisms can occur in the shallow and warm water. As microorganisms such as algae grow, they can use some of the materials in the sewage as food. This helps clean the water, and is an example of bioremediation, the process of using natural substances such as bacteria, to clean a contaminated natural resource, such as water.

WORDS TO KNOW

Beach: Region of sand or rock that slopes down to the water of a lake or ocean.

Bioremediation: The use of living organisms such as bacteria to remove pollutants from natural resources, such as water.

A dwarf treefrog with an inflated airsac sits perched upon a lily pad in Queensland, Australia. *© Pam Gardner; Frank Lane Picture Agency/Corbis. Reproduced by permission.*

Life in and around ponds

Ponds are havens for plants. Because the sunlight is abundant all through the water, plant can grow from every location in a pond. (Plants need sunlight to live as they convert the Sun's energy into food in a process called photosynthesis.) Often, the surface of a pond will be almost entirely covered with pond-loving plants such as the water lily and other plants that need higher levels of sunlight or that need direct exposure to air.

Ponds also support various species of animal life, both in and surrounding its waters. Often, the bottom of a pond will be muddy, rather than rocky, and the mud hosts a variety of living creatures, such as crayfish. The still pond water and muddy bottom are also favorable conditions for the eggs of insects and creatures such as frogs to develop (often attached to the stems or leaves of plants). For microscopic life such as bacteria and algae, a pond offers plenty of food and the sunlit water provides a suitable temperature for the microscopic cells to grow and divide. Animals such as deer often use natural ponds as a source of drinking water. Birds feed upon fish that live in ponds. Beavers find the still pond waters a good place to build their lodge.

Ponds are often a source of relaxation and recreation. In warmer times of the year, a pond's edge can be a place where people picnic or rest outdoors. In the cold winter season of northern climates, ponds can freeze solid and host winter sports such as ice skating.

The fate of ponds

The flow of water into and out of a pond can be slow. This feature, along with its shallow depth, makes a pond vulnerable to contamination. If chemicals that upset the natural composition of the pond are introduced, then the water quality necessary to sustain life can be destroyed. Ponds that form in arid (dry) regions where rainfall is briefly heavy then sparse throughout the rest of the year continue a cycle of filling up, then slowly drying. These ponds attract animal life only when water is abundant, which can sometimes cause conflicts with humans. In some regions of Africa, crocodiles return during the rainy season to newly filled ponds that form near populated villages. Hungry after hibernating (being in an inactive state) the rest of the year, the crocodiles pose a threat to livestock that also drink from the pond, and the people who tend the livestock.

As time passes, the vast majority of ponds will naturally fill in, as sediment (particles of gravel, sand, and silt) and other debris collect in the shallow water. After about one hundred years, what was once a pond often becomes a field, and the water source of the pond is diverted by the changing landscape or by changes in rainfall amounts.

Brian Hoyle, Ph.D.

Famous and Infamous Ponds

Walden Pond is located in Concord, Massachusetts. The pond formed about ten thousand years ago, as glaciers retreated northward from the area. The pond is famous as the inspiration for the writings of Henry David Thoreau (1817–1862). In his book *Walden,* Thoreau wrote about his two-year stay in a small cabin on the shores of the pond, and his reflections on nature have become well known.

Over the years, thousands of people have visited Walden Pond to witness the simple, natural life described by Thoreau. By 1980, tourist activity caused harm to the site that eventually threatened the pond's existence. In the 1990s, rock musician Don Henley of the Eagles organized the Walden Woods Project, which raised millions of dollars for the preservation of Walden Pond.

In Sydney, Nova Scotia, one pond is famous for an entirely different reason. The pond in the center of the community was long used as a dumping ground for the water left over from the nearby steel making plant. The result was a buildup of tons of dangerous chemicals at the bottom of the pond. These chemicals began to leak out of the pond and eventually contaminated the water that flowed underneath a large portion of the community. While the danger has been recognized since the 1970s, a series of governments promised and then backed away from their commitment to remove the hazardous waste. As of 2004, yet another project is planned to clean up what has become known as the "Sydney tar ponds."

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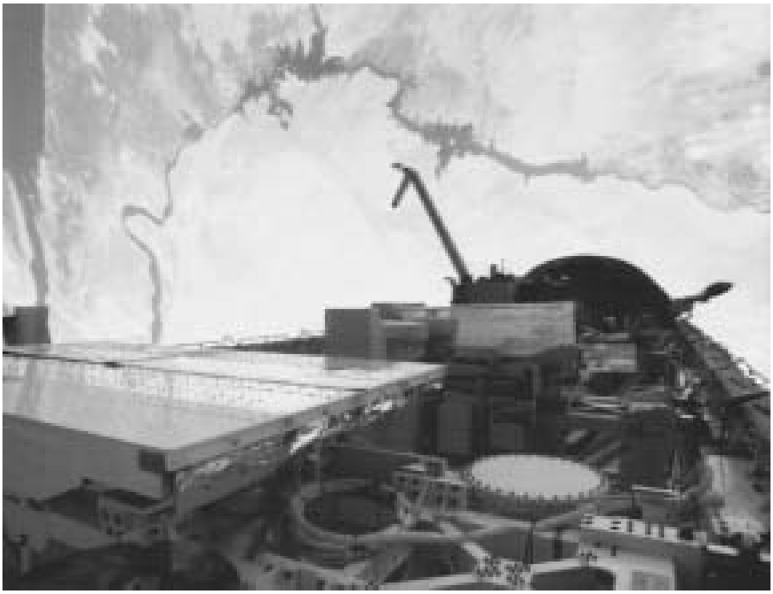
Rivers

Rivers are bodies of flowing surface water driven by gravity. Hydrologists, scientists who study the flow of water, refer to all bodies of flowing water as streams. In common language, it is accepted to refer to rivers as larger than streams. Water flowing in rivers is only a very small portion of Earth's fresh water. The oceans contain about 96% of the water on Earth, and most fresh water is bound up in glacial ice near the North and South Poles. Rivers shape the landscape



The space shuttle *Endeavor* passes over the Nile River. *AP/Wide World Photos. Reproduced by permission.*

WORDS TO KNOW

Delta: The sedimentary deposit that forms at the mouth of a river. Delta means "triangle" in Greek, and river deltas are usually triangular.

Floodplain: Flat land adjacent to rivers that are subject to flooding during periods of heavy rainfall.

Levee: A mound of dirt or articificial barrier constructed to contain the flow of water or to keep out the sea.

River system: A river and its network of headwater streams and tributaries. All the streams that contribute water to the main river.

Sediment: Small particles of gravel, sand, and silt that are deposited by water.

Silt: Sedimentary particles smaller than sand particles, but larger than clay particles.

Watershed: A watershed is the land area that drains water into a river or other body of water.

and are integral to the hydrologic cycle (circulation of water on and around Earth) on the continents.

Rivers shape the lands as they erode (wear away) and deposit sediment (particles of gravel, sand, and silt) along their courses. Running river water acts to level the continents. When geologic forces slowly raise (uplift) mountain ranges, rivers wear them away. The streams that form the Ganges River of India (headwater streams), for example, are presently tearing down the Himalayas almost as quickly as they are uplifted by the movements of Earth's crustal plates (plate tectonics). When geologic forces create depressions or low areas on the continents, rivers act to fill them. River sediment replenishes floodplain (Flat land next to rivers that are subject to flooding) soils and coastal sands. Earth's major rivers, including the Nile, Amazon, Yangtze, and Mississippi, drain the waters of vast continental areas and set down (deposit) huge deposits of sediments at the ends of rivers that flow into the ocean (for example, in deltas at the end of many rivers) Rivers host vibrant communities of plants and animals, and refill groundwater reservoirs and wetlands that support biological life far beyond their banks.

Rivers are a main focus of human interaction with the natural environment. Human agriculture, industry, and biology require fresh, accessible water from rivers. Ancient human civilizations first arose in the fertile valleys of the world's great rivers: the Yangtze and Yellow Rivers in China, the Tigris and

Euphrates Rivers in the Middle East, and the Nile River in Egypt. The distribution of Earth's rivers and systems of rivers has influenced human population patterns, commerce, and conquest since ancient times. Rivers flow through the great cities of the world, and the imagery of rivers is deeply embedded in our language, culture, and history. Today, billions of people depend directly and indirectly on rivers for food and water, transportation and recreation, and spiritual and religious inspiration.

A boat navigates an array of barges along the Mississippi River near New Orleans. *© Royalty-Free/Corbis. Reproduced by permission.*

Almost all major rivers are today confined by man-made dams and levees (walls along the banks) that provide people with the means to generate electricity and protection from floods. These alterations to rivers have come at an environmental cost. When floodwaters are contained by levees or other flood-control dams, they no longer supply nutrients and sediment to floodplain soils that support agriculture. Furthermore, dams and levees that upset a river's natural path and profile (side view) cause changes to the patterns of erosion and deposition (depositing sediments) throughout the entire river system. Dams have contributed to beach erosion on many coastlines because dams trap sediment in reservoirs. Agricultural and urban development along riverbanks has threatened many species of plants and animals that live in riverside wetlands.

Also, the very dams and levees that prevent frequent small floods create an increased risk of infrequent, disastrous flooding. The city of New Orleans, for example, lies at a lower elevation than the bed of the Mississippi River that runs through the center of the city in an artificial channel behind massive levees. If the levees failed, a flash flood would engulf the city and potentially threaten the lives of its residents.

Major rivers

Earth's largest river systems define the natural and human environment within their watersheds. A watershed is the land area that drains water into a river or other body of water. A list of the world's major rivers is also a list of the major natural and cultural geographic regions on six continents. (The continent

The Niger River in Africa. © *Wolfgang Kaehler/Corbis. Reproduced by permission.*

Antarctica is too cold for liquid water. Its fresh water is bound up in large masses of moving ice called glaciers.)

- Africa: The Nile is, by most measurements, the world's longest river. (River lengths are difficult to measure because rivers constantly shift their courses and change length. There is also disagreement about which branches of water (tributaries) are considered part of the main river. By some measurements, the Amazon River in South America is actually slightly longer than the Nile.) The Nile has sustained life in the inhospitable Sahara desert of eastern Africa for thousands of years. Its headwater (uphill end) streams flow from lakes in Ethiopia and Uganda and feed two branches, the White Nile and the Blue Nile, which meet in the Sudanese city of Khartoum. From there, the Nile cuts a green-bordered lifeline through the Egyptian desert. It flows through Cairo, the bustling capital of modern-day Egypt, past the pyramids of Giza and the ancient Egyptian capital of Thebes, to its outlet in the Mediterranean Sea. The Congo River (called the Zaire River from 1971 to 1997) makes a long loop through the equatorial rainforests and war-torn nations of central western Africa. The Congo is the main trade and travel route into the African interior, and it is the setting for Joseph Conrad's famous novel *Heart of Darkness*. The Limpopo, Okavango, Ubangi, and Zambezi are other major African rivers.
- Asia: Huge rivers drain water from the massive Asian continent into the Pacific, Indian, and Arctic oceans. In China, the Yangtze (Chang Jiang), Yellow (Huang He) and Pearl Rivers carry flowing waters (runoff) from the northern slope of the

Himalayan Mountains and western China to the East China Sea. Hundreds of millions of Chinese people depend on these rivers for their electricity, food, and livelihoods. Water moving south from the Himalayas flows into the rivers of India and South Asia, including the Ganges-Bramaputra system and the Mekong River. The Ganges River of northern India is sacred in the Hindu religion. Hindus travel to its banks to meditate and wash away their sins. Upon death, cremated remains are placed into the Ganges in hopes of improving the deceased's fortunes in the afterlife. The Ob, Ikysh, Amur and Lena Rivers run across the northern forests and wind-swept tundra (treeless arctic plains) of Siberia (the Asian portion of Russia) into the icy Arctic Ocean. In the Middle East, rivers play an important role in the history and mythology of western civilization. The ancient civilizations of Sumeria and Mesopotamia arose in the "fertile crescent" between the Tigris and Euphrates Rivers (Shat-al-Arab) in what is today Iraq. Along with the Jordan River, they play major roles in Jewish, Christian, and Islamic history.

- Australia: The island continent of Australia has only a few major rivers, and its central desert, the outback, is extremely dry. The Murray River and its major tributary (major branch), the Darling, make up Australia's largest river system. The Murray drains water from the southeastern states of Victoria, New South Wales and southern Queensland and its floodplains are Australia's most productive farmlands.
- Europe: Rivers are intertwined in the history, culture, and geography of Europe. The capital cities of Europe are synonymous with their rivers (London and Thames, Paris and Seine, Vienna, Budapest and Danube). By their very names, the Rhone (France), Rhine (Germany), Volga (Russia), Oder and Elbe (Germany, Poland, Czech Republic), Po and Tiber (Italy), and Ebro (Spain) conjure images of great art and fine wine, desperate battles and bloody conquests, grand castles and ancient hamlets.
- North America: The Mississippi and its major tributaries, the Missouri, Ohio, and Arkansas Rivers, collect water from a huge drainage basin that spans the central plains of North America between the Rocky Mountains and the Appalachians. Canada's Mackenzie and Churchill Rivers empty into the Arctic Ocean, and the St. Lawrence River empties the Great Lakes into the Atlantic Ocean. The mighty Yukon River of northern Canada and Alaska carried prospectors to mines and mills during the Alaskan gold

The Amazon River

The Amazon River system is Earth's largest body of fresh water. Its basin, in the vast lowlands of equatorial Brazil, contains about one-fifth of Earth's fresh liquid water. So much water flows from the mouth of the Amazon that where it meets the ocean, the ocean water contains mostly freshwater far out to sea. Ships' captains have reported drawing drinkable (potable) water from the sea while still out of sight of land. A dense network of over 1,100 tributary streams and rivers feed the Amazon along its course. Heavy tropical rains regularly overfill the Amazon and its tributaries, and for much of the year the Amazon system more resembles a marshy lake than a system of rivers.

The Amazon River snakes thousands of miles (kilometers) across the widest part of South America, from the slopes of the Andes in Peru, across the tropical rainforest of Brazil to the Atlantic Ocean. Its trunk is miles (kilometers) wide far upstream (even in the dry season), and deep enough for large ships to travel hundreds of miles (kilometers) into the Brazilian rainforest. Native American tribes of equatorial South America each had their own name for their particular stretch of the river or one of its tributaries, and the river was unnamed when Spanish and Portuguese explorers arrived. Spanish explorer Vicente Yañez Pinzon was the first European to sail into the Amazon in 1500, and in 1540, Francisco de Orellana was the first to travel its full length. Orellana named the river "Amazonas" after battling with fierce tribes whose women fought alongside the men. (The Amazons were a tribe of warrior women in ancient Asia and Africa that Greek historian Herodotus described in his writings.

The Amazon basin was then, and is now, a wilderness inhabited by millions of species of plants and animals that thrive in the wet, lush tropical Brazilian rainforest. Scientist estimate that half of Earth's biological species live in the Amazon basin. Swarms of flesh-eating fish called paranhas and 400-pound (181-kilogram) catfish swim beneath towering trees. Jaguars and 30-foot (9-meter) long snakes called anacondas drape across branches. Birds with bright plumage and butterflies by the millions fly in the air.

Today, human agriculture, industry, and land development are encroaching on the Amazonian rainforest. Deforestation (clearing of the forest) and flood control have led to many negative environmental affects, including the rapid extinction of many plant and animal species (biodiversity loss) and addition of greenhouse gases to the atmosphere. Economic development in the Amazon has also negatively impacted the human population of South America, especially the Native American peoples whose cultures and livelihoods are intertwined with the natural cycles of the rainforest. The soils beneath the rainforest are poor, and once the plants and animals are removed, nothing grows well there. South American and international environmental groups, scientists, and some governments and industries are working toward human industry and agriculture in the Amazon that can be sutained over many generations.

rush (1898–99). Many of the great ports of the Atlantic seaboard and Gulf of Mexico lie near river mouths (the end of a river where the river empties into a larger body of water): New York (Hudson), Philadelphia and Washington, D.C. (Potomac, Susquahana), Norfolk (Delaware), New Orleans (Mississippi), and Houston (Brazos). Rivers, including the Mississippi, Missouri, Colorado, Rio Grande, and Columbia, played central roles in European exploration and settlement of the American West. Today, the rivers that carried explorers Meriwether Lewis, William Clark, John Wesley Powell, and other legendary frontiersmen across the continent are used for agricultural irrigation, drinking water, recreation, and power generation. Their water is a valuable and heavily-sought resource.

- South America: The Amazon is the largest river in the world. It flows from the Andes Mountains of Peru, across the Brazil and empties into Atlantic Ocean on the northeast coast of Brazil. The Amazon has more than 1,100 tributaries, 17 of which are longer than 1,000 miles (1,609 kilometers) long. The main river runs from west to east just a few degrees south of the equator, and its massive watershed lies entirely within the warm, wet tropical zone. The central Amazon contains Earth's lushest, wettest, most biologically diverse rainforest. The Orinoco (Venezuela), Sao Francisco (Brazil), Parana (Argentina, Paraguay) and Uruguay (Uruguay, Brazil) rivers are other major waterways of South America.

Laurie Duncan, Ph.D.

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Stream Systems

Streams are any size body of moving surface fresh water driven towards sea level by gravity (force of attraction between two masses). Water scientists refer to all bodies of flowing sur-

WORDS TO KNOW

Braided stream: Streams with many channels that spit apart and rejoin.

Channel: The water-filled path of the stream at a specific point in time.

Divide: High point or ridge that separates drainage basins, and in which water flows down in all directions.

Floodplain: Flat areas bordering a river that are subject to flooding when water overflows the stream channel.

Levee: A natural or man-made wall along the banks of a stream channel that helps confine floodwaters within the channel.

Meandering stream: A stream with a channel that follows a twisting path of curves and bends.

Stream: Moving surface fresh water driven towards sea level by gravity.

Watershed: The land area that contributes runoff to a stream system; also called drainage basin.

face water as streams regardless of size, yet in common language, streams are considered smaller than rivers. Stream systems are networks that collect fresh water runoff from the land and carry it to the ocean. Together, tree-shaped systems of small branch streams drain vast areas of the continents into large rivers. Stream systems of all sizes erode (wear down) sediment (particles of gravel, sand, and silt) along their courses and carve complex patterns into the landscape. They wear down slow-rising mountains and fill valleys and lowlands (low and level lands) with layers of sediment. Stream systems change character along their courses. Steep mountain streams feed shallow elevated streams that in turn flow into meandering rivers that snake across broad floodplains (flat, low-lying land near a stream that is covered with water when the stream overflows its banks). Deposits of sediment form at river mouths, the area where fresh river water enters the ocean.

If a rubber duck was dropped into a mountain stream on Pike's Peak in Colorado, it might tumble down the mountainside in whitewater rapids to Cripple Creek. From there, the duck would rush over gravel beds where Colorado miners once panned for gold, and then float serenely across Kansas, Oklahoma, and Arkansas on the Arkansas River. It would pause to drift across huge man-made reservoirs, and then plunge through the spillways of dams before entering the swift, muddy waters of the Mississippi River. A few weeks or months later, you might spot the duck heading out to sea amid barges and river boats in New Orleans.

Watersheds and drainage patterns

The land area that drains water into a stream is called a watershed or a drainage basin. A basin is a natural depression in the surface of the land. Watersheds can be as small as a hillside that feeds a wet-weather creek, and as large as a drainage system like the Amazon Basin that carries the runoff from most of a continent. Large watersheds are composed of many smaller drainage basins. The boundaries between watersheds, called drainage divides, are ridge lines or high points where water flows down and away in all directions. A divide can be limited, like a ridge between two mountain gullies (deep ditches or channels cut in the earth by running water, usually after a rainstorm), or extensive, like the North American Continental Divide along the spine of the Rocky Mountains. Water that falls east of the Continental Divide eventually flows into the Atlantic Ocean, and water that falls west of the Rockies ends up in the Pacific Ocean.

Control of Nature on the Mississippi River

The Mississippi River system is a huge network of streams and rivers that drains water from the North American Plains between the Rocky Mountains and the Appalachians. (The word Mississippi probably comes from Chippewa Indian words that mean "great river" or "father of waters.") The Mississippi River and its tributaries, which include the Ohio, Missouri, and Arkansas Rivers, are the central arteries of the North American Interior. Stream waters of the Mississippi system have eroded tall mountain ranges, deposited fertile soils of the American Mid-West, and constructed the massive Mississippi River Delta in the Gulf of Mexico. The rich ecosystems (communities of plants and animals) of the American Plains have have adapted not only to the river waters but to its massive floods and ever-changing course.

Humans too have thrived within the Mississippi watershed. Native Americans of many nations including Ojibwe, Choctaw, Winnebago, and Chickasaw had been hunting the plains and living on the banks of the Mississippi for centuries before Spanish conquistador Hernando de Soto became the first European to see it in 1541. White settlers arrived by the riverboat load throughout the 1800s to farm the rich floodplains of the Mississippi, Ohio, Missouri, and Arkansas Rivers. Today, crops grown in the fertile soils of the American Midwest feed millions of people around the world.

The modern-day Mississippi River is one of the most carefully controlled natural features on Earth. The very floods that deposited the rich soils of the American Midwest threaten human property, crops, and even lives. Following devastating floods in the 1930s, the U.S. Army Corps of Engineers constructed artificial levees along the length of the river. The levees straightened the channel and prevented its natural side-to-side migrations. Once annual floodwaters were confined behind levees, they drained wetlands along the river's edge, and agricultural and urban development increased on the floodplains.

Flood control measures have allowed for extensive development, productive agriculture, and some security against flooding. Like many human attempts to fight nature, however, the Mississippi levees have exposed people to new risks, and have taken a toll on ecosystems that live within the watershed. Levee failures, like the ones that occurred across the Midwest in 1993, can result in catastrophic flooding of heavily populated areas and valuable cropland. Many plant and animals species, especially birds, have suffered near extinction because of the loss of their wetland habitats. Without the nourishing blanket of silt they received every spring from floodwaters, Midwestern soils are losing their fertility leaving farmers more dependent on chemical fertilizers.

Streams are arranged within watersheds in networks that feed water into larger and larger streams. Tree-shaped (dendritic) systems composed of small branch tributaries (small streams that flow into larger streams) that join and flow into large trunk streams are the most common type of stream drainage pattern. Less common drainage patterns develop where rock layers and geologic features affect the paths of streams. Drainage patterns shaped like cross-hatched garden trellises develop in hilly areas where there are ridges and valleys, and streams flow out from round volcanic mountains in radial patterns like spokes on wheels.

Valley and channels

Streams cut down into the land surface and create valleys. A stream valley includes the entire area between hills on either side of a stream. The water-filled path of the stream at a specific point in time is called a channel. Over time, channels migrate back and forth and fill stream valleys with thick layers of river sediment. Some streams, particularly those in steep, mountainous terrain have narrow, V-shaped valleys and channels that fill most of the valley floor. Others, including most streams in gently-sloping basins and coastal lowlands have narrow channels that snake across wide sediment filled valleys. For example, the Mississippi River has carved a valley more than 100 miles (161 kilometers) wide and filled it with sediment hundreds of feet (meters) thick over thousands of years.

Channel patterns

Stream channels assume different patterns within their valleys: straight, braided and meandering. While many channels have straight segments between meanders or braids, truly straight channels are quite rare. They develop in steep, mountainous areas where geologic forces are slowing lifting up the land surface. Water flowing rapidly downhill from mountains saws straight channels down into solid rock.

Braided streams have many intertwined channels and islands of loose gravel that constantly shift across gravel-filled valley floors. They are common in streams that receive large pulses of water and course-grained sediment. The sediment-choked streams that carry water from the toes of melting glaciers are typically braided.

Streams that bend and curve across gently sloping valleys and coastal plains are called meandering streams. (Individual loops and bends are called meanders.) During normal weather conditions, water flows in a narrow channel that snakes across broad plains of soft sediment. During floods, muddy water overflows the banks of the channel and deposits layers of mud and silt on the surrounding floodplains. River floodplains are typically fertile farmlands that have been replenished by floodwaters. The coarser grained sediment settles out of flood waters closer to the channel builds natural levees (walls along the banks of a stream channel) along its banks.

Stream piracy, when one stream captures water from another stream, can alter the course of streams and impact local ecosystems. © *Roger Wood/Corbis. Reproduced by permission.*

The path of a meandering channel changes over time. Meanders grow from slight bends into nearly-circular loops. At a river bend, fast-flowing water erodes the outer channel bank and sediment accumulates on the inside of the curve in a deposit called a point bar. Eventually, the bends at the neck of the meander grow so close that the water bypasses the loop. This process strands crescent-shaped segments of the former channel and round point bar deposits called oxbows on the floodplain. Oxbow lakes are abandoned meanders that contain water.

Channel patterns change down the course of a stream system between headwater streams and lowland trunk rivers. They also change over time as streams adjust to changing conditions of water flow, land incline, and amounts of sediment. Stream waters continuously erode and deposit sediment over time, and stream channels constantly shift across valley floors.

Laurie Duncan, Ph.D.

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Stream Water Flow

Water flows downhill due to Earth's gravity (force of attraction between two masses) pulling it. Streams, like rivers, are gravity-driven bodies of moving surface water that drain water from the continents. Water scientists, called hydrologists, refer to all bodies of running water as streams, no matter their size so, in one sense, rivers are large, well-established streams). In everyday communication, it is common to refer to streams as smaller than rivers.

Streams transfer water that falls on the land as precipitation (rain, snow, sleet, and hail) to the oceans. Streams, again like rivers, constantly shift their courses and change length. The stream is carried along a defined path, called a channel. Water flowing in stream channels is a powerful sculptor that carves landscapes and molds sediment (particles of rock, sand, and silt). It wears down mountain ranges and cuts deep canyons through solid rock. Stream waters support vibrant communities of plants and animals, and they have been the lifeblood of human civilization for thousands of years. Streams shape the land and are also integral to the hydrologic cycle (circulation of water on and around Earth).

Erosion and deposition

Streams are the main agent of erosion (wearing away) on land. Water in fast-moving streams is usually turbulent. The flowing water is filled with swirls and small localized

WORDS TO KNOW

Base level: The water level at the outlet of a stream, usually sea level; streams cannot erode below this level.

Channel: The path the stream is carried along.

Current: A concentrated flow of faster-moving water within a stream.

Deposition: Laying down sediment to produce an accumulation called a deposit.

Dissolution: When water breaks rocks into dissolved chemicals; a form of erosion.

Erosion: Wearing down of rocks and other materials by natural forces.

Graded profile: A stream with a constant slope (incline).

Graded stream: A stream that has achieved a constant slope (profile) by reaching a balance of erosion and deposition.

Precipitation: When chemicals dissolved in water join to form solid crystals; a form of deposition.

whirlpools of swirling water called eddies. Turbulent water picks up particles of sediment that have weathered from rock and soil and carries them downstream. (Weathering is the breaking up of rocks by physical and chemical processes, such as being exposed to the actions of water, ice, chemicals, and changing temperature.) Faster-moving water can carry more sediment in the water, and can push larger stones along the bottom of the channel. Some mountain streams move huge boulders, while sluggish lowland (low country and level) streams carry only fine grains of silt and mud. The sand grains and larger rock fragments that slide and bounce along stream beds wear away solid rock. In a straight stream, the fastest-moving water and area of greatest erosion is generally in the middle of the channel. Where a stream bends, the strongest current (a moving mass of water) is on the outside of the curve.

Storm drains overwhelmed by water following a heavy rain storm. *AP/Wide World Photos. Reproduced by permission.*

When water slows down, it drops its sediment load, causing sedimentary deposits to form along stream courses in areas of slow-moving water. The slower the current, the finer the sediment it deposits. In straight channels, stream water lays down sediment along the stream banks. In bending channels, sedimentary deposits called point bars form on the inside of the bends. Individual sediment grains travel downstream like hitchhikers. Sometimes the grains are picked up by a strong current or flood that moves them far downstream, but usually they don't go very far in a single trip. The grains of sand on a beach each made a long trip with many stops before they arrived at the ocean. Whether an individual grain of sediment moves depends on the speed of water currents that vary as the amount of water moving through a stream changes. As water currents become faster they can move larger grains.

Stream waters also erode rocks by dissolving its minerals, which causes them to crumble. Chemical weathering, also called dissolution, occurs when the slightly acidic water chemically alters the minerals in rocks, which causes them to break down. Clear stream water carries the chemical components (parts) of the rocks' minerals called ions (electrically charged

Victoria Falls

Victoria Falls near the border of Zimbabwe and Zambia. *Cynthia Bassett. Reproduced by permission.*

Victoria Falls is a curtain of thundering water where the mighty Zambezi River tumbles over high cliffs in central Africa near the border between Zambia and Zimbabwe. It is the largest, and arguably the most beautiful waterfall on Earth. (Angel Falls in Venezuela is the world's tallest waterfall.) Victoria Falls is one of the seven wonders of the natural world. Travelers journey there to see its incredible wall of tumbling water and clouds of billowing mist that shimmer with rainbows. The roar of falling water can be heard 20 miles (32 kilometers) away, and a rainforest filled with rare plants and animals grows in the mist.

Legendary British explorer David Livingstone (1813–1873) was the first European to see what local people called "the smoke that thunders" in 1855. In his journal Livingstone wrote of the falls, "No one can imagine the beauty of the view from any thing witnessed in England ... scenes so lovely must have been gazed upon by angels in their flight." Livingstone named the falls after Queen Victoria.

Victoria Falls is a striking example of the power of flowing water. The Zambizi River carved the chasm beneath the falls by eroding away a weak rock layer. The cliff behind the falls is composed of rock that better withstands the force of the water. Victoria Falls has been moving upstream as the turbulent whitewater in its base erodes away the base of the cliff.

particles). When conditions in the water change (the water slows or cools), the ions recombine into solid mineral crystals. This form of sedimentary deposition is called precipitation. Limestone, salt, and gypsum form by precipitating from water. Ocean animals like corals and shellfish take in ions and use them to build their shells. Some types of rocks, including chalk and flint (also known as chert) form from the remains of organisms.

Graded streams and base level

All streams strive to reach a constant slope (incline) called a graded profile by eroding and depositing sediment. The profile (side-view) of a graded stream (a stream with a graded profile) is steep near the uphill end and gently sloping near the point at the end where a stream pours its water into a larger body of water. The position of the downstream end of the profile is

Flash Floods

A flash flood swamps a car in muddy water. © *Royalty-Free/Corbis. Reproduced by permission.*

Flash floods are deadly. They can occur with little or no warning after a heavy rain, a dam or levee (a protective barrier built along the banks of a stream to prevent flooding, often made of dirt) failure, or release of a log or ice jam in a river. In many ways, flash floods are like all floods. They happen when water overfills a stream channel and spills into areas that are usually dry. Like all floods, they often damage property, drown crops, and pollute drinking water. Unlike other floods, flash floods rise to catastrophic levels within hours or even minutes, and leave people little chance to escape rushing water.

Intense rainstorms that cause flash floods often occur in small area within a larger stream system. The surge of water rushes down through the system through areas that received no rain, causing flash floods to often occur under sunny skies and in dry regions. Flash floods are a particular hazard to hikers and other people in the canyons of the American Southwest. Summer thunderstorms can temporarily turn the dry, steep-walled canyons of the desert southwest into raging streams. The rushing flood waters travel downstream so quickly that downstream victims do not receive warning, even with modern communication systems. Flash floods kill more people than any other weather-related events in the United States.

determined by the water level at the outlet, called base level. Streams cannot erode below base level. Almost all stream systems run to the sea, so sea level is the ultimate base level for most streams.

Conditions change constantly in all streams, and the process of readjustment by erosion and deposition is ongoing. As conditions change along its course, a stream will readjust its profile by eroding sediment in some places and depositing it in others. If base level falls, stream waters cut down into the land surface. If it rises, they deposit more sediment. If the movements of the underlying plates of Earth's crust rise (geologic uplift) to steepen the upper part of a stream, it will erode down to regain its graded profile. Streams also attempt to level out obstructions along their path. They work to tear down dams, both natural and man-made, by erosion and filling the reservoir behind it with sediment. Lakes are, therefore, only temporary features of stream systems, and dams are interrupting the natural flow of a stream's water.

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Chapter 4
Estuaries and Wetlands

Estuaries

Estuaries are the areas where rivers run into oceans. They often exist where the opening to the sea is somehow obstructed, for example by a sandbar or a lagoon (sandbars are ridges of sand built up by water; lagoons are shallow areas of water separated from the ocean by sandbars or coral). The water in estuaries is dominated by the flow of the tides. When tides are high, the ocean water washes through the estuary bringing with it sediments (particles of sand, silt, and gravel), nutrients, and organisms from the ocean. When the tide is low, the freshwater of the river floods the area, releasing its load into the estuary. Because estuaries exist where two different types of water come together and where the land meets the water, estuaries provide many different types of habitats for animals and plants. In addition, both the river and the ocean bring estuaries nutrients such as nitrate and phosphate, which plants need to grow. This results in a complex range of plants and animals that thrive there. Estuaries are also important to human settlement and economics. As a result, estuaries are often subject to pollution and other environmental stresses.

General structure of an estuary

The part of the estuary farthest from the ocean is often called a salt marsh. (A marsh is a wetland dominated by grasses.) Water usually flows through salt marshes in tidal creeks. Unlike river water, the water in tidal creeks can flow in two directions. When the tide comes in, the water runs into the salt marsh and when the tide goes out, the water runs the opposite direction, away from the salt marsh.

WORDS TO KNOW

Brackish: Water with salinities between freshwater and ocean water.

Halocline: Layer of water where the salinity changes rapidly with depth.

Marsh: Wetland dominated by grasses, reeds, and sedges.

Nutrients: Compounds like phosphate and nitrate necessary for plant growth.

Osmosis: The tendency for water to have the same concentration on both sides of a membrane.

Phytoplankton: Free-floating plants, mostly microscopic.

Plankton: Free-floating animals and plants, mainly microscopic.

Salinity: The concentration of salt in water.

Zooplankton: Free-floating animals, mostly microscopic.

The part of an estuary closer to the ocean may contain mudflats (a thick, flat layer of mud or sand that is usually underwater at high tide) and sandbars. These areas are exposed when the tide is out and may be covered with water when the tide is in. They are often covered with a layer of thin algae, which are tiny rootless plants that grow in sunlit water. Many different types of burrowing (digging holes or tunnels) creatures, like clams and worms, live on mudflats and sandbars. Birds often walk along mudflats and sandbars when the tide is out, hunting for prey (animals hunted for food) buried in the ground.

The ocean edge of the estuary is almost always covered with water, although its depth changes with the tides. In this region, river water and ocean water mix and the resulting water has a salinity (the concentration of salt in water) that is neither fresh nor seawater. This type of water is called brackish. Brackish water includes water of a large range of salinities, from freshwater, which is about 0.5 part salt per thousand parts of water (ppt) to seawater, which is about 35 ppt.

The ways that the freshwater and the ocean water mix within the estuary is often very complicated. Sometimes the freshwater sits on top of the ocean water, because it is less dense. When this occurs, a halocline forms between the two types of water. (The root word *halo* means "salt" and the root word *cline* means "change.") A halocline is a layer of water where the salinity changes very quickly. The halocline can act as a physical barrier between the freshwater on top and the saline water below, blocking the exchange of nutrients, and even organisms, between them.

Life in estuaries

Brackish waters pose one of the most important challenges for many animals and plants living in estuaries. Because the salinity of the water is constantly changing, their cells must be able to handle osmotic changes. Osmosis is the tendency of water to have the same concentration on both sides of a material that allows liquid to pass (like a cell membrane, the structure surrounding a cell). When exposed to fresher water, cells that have grown accustomed to waters that are more saline will take in water, expand and even burst. When exposed to more saline conditions, cells that have grown accustomed to fresher water will release water, shrivel, and perhaps die. There are a variety of animals and plants that have special adaptations so that they can live in waters with changing salinities and these organisms thrive in estuaries.

A second problem facing organisms that live in estuaries is the ever-changing water level. Because the tide goes in and out, animals and plants must be able to handle waterlogged environments as well as environments that are dry. Many animals burrow in the sand and mud in estuaries. For example, sea cucumbers and polychaete worms live in holes in the mud. They expose their tentacles to the water where they capture plankton (free-floating organisms) and small prey that float into their reach. When the tide goes out, they burrow into their holes where they can stay moist.

Plant life in estuaries The salt marsh region of the estuary is characterized by plants that are adapted to salty conditions. The high salt marsh cordgrass has special organs on its leaves that remove the salt it takes up from its roots. The eelgrass, *Spartina,* looks like a grass with very tough leaves and stems that help it retain moisture in saltwater. It can be found in salt marshes throughout the East Coast of the United States. Other common salt marsh plants are sea-lavender, scurvy grass, salt marsh grass and sea-aster.

Farther out in the deeper waters of the estuary, microscopic phytoplankton (tiny plants that float in fresh or saltwater) are some of the most important plants. These single-celled algae-type plants float near the surface of the water where sunlight is available. Because the ocean water and the river water both deposit the nutrients that phytoplankton needs to grow quickly, phytoplankton in estuaries flourish. The large populations of phytoplankton are food for zooplankton (free-floating animals, often microscopic). In turn, the phytoplankton and zooplankton are meals for worms, clams, scallops, oysters and crustaceans (aquatic animals with jointed limbs and a hard shell).

Animal life in estuaries Because the types of habitats in estuaries are so diverse, estuaries are home to many different species of animals. Worms, clams, oysters, sea cucumbers, sea anemones and crabs all make their homes in the muddy floor of the estuary. Many of them burrow in the mud and filter the water for plankton and small fish that swim within the grasp of their tentacles and claws.

In some places, the clams and oysters become so numerous that their shells provide special habitats for other small animals. Barnacles grow on oyster shells in oyster beds. Small fish, snails, and crabs will hide from larger predators in the crevasses between clamshells. Mosses and algae will grow on the surfaces of some molluscs, providing food for the animals that take refuge there.

Grasses grow along the banks of an estuary of the Chesapeake Bay. © *Raymond Gehman/Corbis. Reproduced by permission.*

A variety of fish live in estuaries. Very small fish called gobies hunt along muddy and rocky surfaces for small crustaceans like shrimp. Long slender fish called pipefish swim among the grasses in the marsh, their shape blending in with the long blades of the plants. Larger fish like halibut and flounder, swim along the muddy floor, their flattened shape allowing them to move into the shallow regions of the estuary. Large predatory fish like redfish, snook, striped bass, mullet, jack, and grouper make their way into estuaries to feed on the rich supply of fish that can be found. Salmon pass through estuaries on their way up rivers to breed.

Many fish and invertebrates (animals without a backbone) use the estuary as a nursery ground for their young. For example, in Florida, a variety of species of shrimp spawn in the ocean, and their larvae (immature young) travel to the mouth of the estuary, where they develop into young shrimp. At a certain stage of their development, they ride the tide into the estuary, where they live among the eelgrass. The eelgrass provides them with protection from predators and the rich nutrients in the estuary produce plenty of food for them to eat. Once the shrimp become adults, they swim back to the ocean, where they spawn, producing young that will move back to the estuaries again.

Birds are extremely numerous in estuaries. During low tides, a variety of shorebirds walk along mudflats, pecking their beaks into holes where worms, crabs and clams are buried. Herons scour the shallow waters for shrimp and small fish. Brown pelicans, an endangered species, use estuaries as breeding grounds and nesting areas for their young.

Importance of estuaries

Estuaries are a unique habitat for a large variety of animals and plants. Because of their complexity a broad variety of species live in estuaries, either for part of their lives or for their entire life. The U.S. Department of Fisheries estimates that three-quarters of the fish and shellfish that people eat depend on estuaries at some point during their lives. Oysters, clams, flounder, and striped bass may live their entire lives within estuaries.

Estuaries serve as a buffer from flooding and storm surges. The soil and mud in estuaries is absorbent and can absorb large quantities of water. In addition, the roots of the grasses and sedges (grass-like plants) in estuaries are able to hold together sediments and protect against erosion (wearing away of land). Estuaries provide important protection to the real estate in many coastal communities.

As water moves through an estuary it is naturally filtered and cleaned. The many plants and bacteria that live in the estuary use pollutants, like agricultural fertilizers, to grow. Sediments that are transported to estuaries by rivers tend to settle into the estuary, where they act as filters, allowing cleaner water to flow into the ocean.

Chesapeake Bay

The largest estuary in the United States is Chesapeake Bay. It is an environment that has affected and been affected by humans for hundreds of years. Native Americans lived on the estuary and used it for its rich resources for thousands of years before Europeans came to North America. Once the colonists arrived, they began changing the landscape. By 1750, about one-third of the forests surrounding the estuary had been cleared. By 1865, more than half were gone. As cities and towns grew up along the Bay in the 1900s and into the 2000s, even more land was cleared for houses and commercial developments. With more and more people living near the Bay, the environmental stresses have become increasingly harmful.

Since the 1970s, both legislators and the people who live near the Chesapeake Bay have been actively involved in protecting the bay from environmental stresses. The Chesapeake Bay Program has worked to reduce pollution, to restore water quality and habitat, to manage the fisheries, to monitor the Bay ecosystems (the network of interactions between living organisms and their environment), and to develop practices that use the land in the best possible ways.

Danger to estuaries

Bacteria can break down some, but not all pollutants and many pollutants are not taken in by plants. Pollutants can build up to harmful concentrations within estuaries that threaten the health of the birds, fish, and humans that live nearby.

There are four major types of environmental stresses that affect Chesapeake Bay, the largest estuary in the United States. The most damaging type of pollution to the Bay is the input of nutrients like phosphate and nitrate, which are fertilizers used in agriculture. High concentrations of nutrients enter the Bay as rainwater runoff from land and from sewage treatment facilities. Although they are required for plants to grow, high concentrations can cause overgrowth of algae and marsh plants.

Students trap sea life in a net as part of a one-day workshop at the Estuaries Environmental Studies Lab in Edgewater, Maryland. Participants learn how to conduct studies of Chesapeake Bay. © *Lowell Georgia/Corbis. Reproduced by permission.*

This overgrowth can result in the plants using up all the oxygen in the water, causing the fish to die.

A second type of pollution is the input of sediments like clay, sand, and gravel that enter the Bay through river runoff. Although sedimentation is a natural occurrence, increased rates of erosion sometimes cause large amounts of sediments to be deposited in the Bay. Sediments can clog the feeding apparatus of filter-feeding animals and can cloud the water making it more difficult for plants to get light.

Air pollution is a third source of stress on the bay. Pollutants released from factories and cars as exhaust eventually make their way to the bay. Some of these pollutants produce acid rain, which changes the acidity of the bay, while others contribute to the concentration of nitrogen in the bay. Although evidence shows that dangerous pollutants, a fourth stress on the environment of the bay, are currently not as damaging as the other forms of pollution, the release of chemicals into the bay from some of the industries in the region can be deadly to both animals and plants.

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Wetlands

Wetlands are areas of land where water covers the surface for at least part of the year and controls the development of soil. Plants and animals that live in wetlands are adapted to living in conditions where the soil is waterlogged. There are many different types of wetlands, but they fall into five general classifications: freshwater marshes, freshwater swamps, salt marshes, mangrove swamps, and bogs (also called fens). In general, swamps have trees, while marshes have plants that have soft stems like grasses, reeds, and sedges (grass-like plants). Bogs are characterized by thick mats of peat, which is made of mosses growing on decayed plants and animals.

Freshwater marshes

Freshwater marshes are found on the edges of lakes, ponds, and rivers. They are particularly common near the floodplains of rivers. About one-quarter of all the wetlands in the United States are freshwater marshes.

WORDS TO KNOW

Eutrophication: The process of large quantities of nutrients in an aquatic environment resulting in excessive growth of aquatic plants and algae and a low oxygen content of the water; eventually leads to loss of life.

Mangrove: Tree that grows along coasts in salt water.

Mangrove swamps: Swamps found on the edge of oceans in tropical (hot) regions.

Marsh: Wetland dominated by grasses, reeds and sedges.

Peat: Compressed organic material found in bogs.

Photosynthesis: The process by which plants use sunlight, water, and carbon dioxide to produce their food.

Sedge: Grass-like plants.

Swamp: Wetland dominated by trees.

A sign warns motorists of frequent duck crossings. © *Alan Schein Photography/Corbis. Reproduced by permission.*

Plants that grow in freshwater marshes have adapted to survive in waterlogged conditions. They do not need stiff stems to hold them up because the water provides buoyancy (the ability to float). Water lilies are typical plants that grow in freshwater marshes and they have flexible stems that bend and straighten as the water level changes. The leaves of the water lily float on the surface of the marsh. Because the roots of freshwater marsh plants are often underwater or in mud, they are frequently exposed to low oxygen concentrations. They have developed spongy stems full of air spaces that can transport oxygen to the plant roots. Some marsh plants, like duckweed, don't have roots at all. They float and absorb minerals from the water.

Animals that live in freshwater marshes have also adapted to use their wet environment to their advantage. Many of the insects that live in freshwater marshes have aquatic stages that take up a majority of their life. For example, dragonflies spend up to five years as larvae that live underwater. The adult fly stage only lasts for one season. Many birds make the marsh their home. Often, birds like the American bittern are striped and well-camouflaged by the marsh grasses. Other birds, like the herons, have extremely long legs and wade through the marsh hunting for fish. Ducks are especially common marsh birds. They have special organs that produce oils to waterproof their feathers. Nearly three-quarters of all ducks in North America breed in freshwater marshes in prairies.

Freshwater swamps It is estimated that about two-thirds of all wetlands in the United States are swamps. Trees are the dominant plant in this environment and the trees species found in swamps vary depending on location. In the northern part of North America, evergreens such as spruce, fir, and cedar are commonly found in swamps. In New England, red maple dominates. Black willows and cottonwoods dominate swamps along the Mississippi and Connecticut rivers. In the southern part of the United States, bald maple, tupelo, and sweetgum trees are commonly found in swamps. The bald maple produces knobs that look like knees that are probably used to acquire oxygen for the roots of the trees, which are buried in mud that has no oxygen. Bald maples, tupelos, and sweetgum trees also grow buttresses (support limbs) that help hold up the trees because their roots are close to the surface of the mud where oxygen is a little more accessible.

Trees are crucial to the ecology (relationships between living organisms and their environment) of the freshwater swamp. Because many of the trees that live in swamps lose their leaves each fall, swamp water is highly enriched from decomposing plant material. Many worms, newborn insects, and crustaceans (aquatic animals with no backbone and a hard shell) live by cutting apart fallen tree leaves for food. Bacteria break down the leftovers and produce nutrients (substances necessary for plant and animal growth) for other animals. These animals attract birds, snakes, and mammals to swamps. In addition, trees provide important hiding places for birds. Woodpeckers drill holes in trees and use them for nests. After the woodpeckers abandon their holes, other birds like owls, titmice, and wrens take over. As trees die and fall over into the swamp waters, ducks and snakes use rotted holes for their homes.

Salt marshes Salt marshes are marshes that are found along ocean coasts. One of the most important features influencing salt marshes is the tide that goes in and out each day. When the tide is high, marsh grasses, algae, mussels, crabs, snails, and worms are covered in cool, salty water. When the tide is low, these same organisms may bake in the sun. The animals that live in salt marshes have developed different adaptations to overcome these extreme changes in environment. Land snails crawl up and down the stems of marsh grasses keeping away from the water as the tide goes up and down. Land crabs dig burrows (tunnel or hole) in the mud, which they seal up to protect themselves from the waters of the high tide. Marine (ocean) snails scurry into pools in the sand and close their shells tightly as protection from drying out during low tide.

Salt marshes are places of great biodiversity (variety of life) and productivity. Nutrients circulate into salt marshes from the ocean and rivers. In addition, as plants and animals die and are buried in the marsh, bacteria digest and convert them into nutrients. All of these nutrients support an enormous amount of plant growth. One acre of salt marsh can produce 4.8 tons (4.3 metric tons) of plant material each year, almost twice that of a corn field given fertilizers. This plant growth, in turn, supports many species of invertebrates (animal without a backbone), fish, and birds.

Mangrove swamps

Mangrove swamps are swamps found on the edge of oceans in tropical (hot) regions. Mangrove swamp water is salty and the plants and animals that live in mangrove swamps have unique characteristics that allow them to handle these salty conditions. Many of the plants that live in mangrove swamps have special organs that remove salt from their tissues. In addition, many of the sediments (particles of sand, gravel and silt) in swamps are low in oxygen, so plants must be able to adapt to low oxygen levels.

Mangroves are trees that can tolerate saltwater. Many mangroves have special adaptations to gather oxygen from the air. There are a variety of different species of mangroves and they each grow best in slightly different environments. In North America, red mangroves are found closest to the water. They have tough roots called prop roots that help anchor them to unstable sandy soils in shallow water. These roots trap sediments and also provide habitats for juvenile fish and invertebrates. In particular, oysters, anemones, snails, and snakes all live attached to red mangrove roots. Red mangroves have special pores called lenticels in their stems that they use to take in oxygen. Black mangroves are found behind the red mangroves, closer to land. They have special roots that grow like spikes out of the swamp water to gather oxygen from the air. White mangroves are found closer to the land behind black mangroves. On the edge of the swamp that is closest to land, a mangrove called a buttonwood is most common.

Many birds and mammals make their homes in mangrove swamps. Roseate spoonbills, ibis, and pelicans are all commonly found digging their bills into the swamp sand hunting for fish and invertebrates. Egrets, herons, and spoonbills also use the mangrove canopy for nesting, in order to avoid predators such as mammals and fish. Rabbits and raccoons are land mammals that can be found in mangrove swamps. The manatee is a marine mammal that makes its home in the swamps of Florida. It is herbivorous (plant-eating), and grows to enormous sizes (3,500 pounds or 1,600 kilograms). Manatees are classified as an endangered species; the greatest threat to their existence is boat propellers.

Bogs

Bogs are unusual environments. They occur near springs, slow-moving streams or small ponds. Water in bogs is usually very acidic, and because bacteria generally do not grow well in acidic environments, bog water has few bacteria. As a result, dead plant material is not decomposed; instead it piles up, pressing down on layers of plant material below it. This produces peat, which is so thick and solid that it can be used like coal for fuel. As bogs are waterlogged, they do not become solid and walking across a bog feels like walking across a waterbed.

Some species of moss and sedge (a grass-like plant) can grow on top of the peat. Most of these plants have adapted to take in oxygen from the air because the soil in a bog is usually low in oxygen. One of the most important bog plants is called sphagnum moss. Sphagnum moss is acidic and thus, few bacteria grow on it. Besides its antiseptic qualities, sphagnum moss. is highly absorbent and was used extensively for bandages during World War I (1914–18). It is soft and spongy; dry sphagnum moss can absorb water until it weighs as much as twenty times its original weight. Native Americans frequently used sphagnum moss for baby diapers.

With few bacteria living in acidic bog waters, decomposition occurs slowly and nutrients remain locked inside dead plant material. Plants that do grow in bogs must be creative in order to get nutrients. Many species of carnivorous (meat-eating) plants live in bogs. They receive nutrients from the prey that they capture, mostly small insects, but still use photosynthesis (process of producing food using sunlight) to generate sugars. Some examples of carnivorous bog plants are Venus flytraps, bladderworts, and pitcher plants.

Importance of wetlands

Wetlands are places of great biological diversity. In swamps and marshes, the water is shallow enough that light can penetrate to the bottom, meaning that a great deal of photosynthesis can take place. This, in turn, leads to many different types of herbivorous animals, considered the primary consumers, and animals that in turn eat the herbivores, considered the secondary consumers. Wetlands are very important breeding grounds for both fish and invertebrates. Nearly two-thirds of all shellfish and bony fish in the ocean rely on wetlands for some part of their lives. About one-third of all endangered species spend time in wetlands, according to the U.S. Fish and Wildlife Service.

Wetlands have several important ecological roles. Because of their ability to trap water, they act as sponges during heavy rains, slowing the flow of water into rivers and minimizing floods. This decreases erosion (wearing away of land) while protecting homes and other structures that could otherwise be flooded with water. In addition, this slowing of rainwater allows some of it to seep into aquifers (underground basins containing fresh water), which replenishes the source of much drinking water. Wetlands also greatly reduce pollution and a process called eutrophication. Eutrophication is the process of water becoming enriched with nutrients, causing a population explosion of aquatic plants and reducing the oxygen in the

Some communities build boardwalks so that residents can enjoy wetlands without damaging the fragile environment. *© Cathrine Wessel/Corbis. Reproduced by permission.*

water. This results in the loss of animal and plant life. Wetlands absorb many of these nutrients, allowing plants—which take in pollutants—to grow.

Wetlands are not permanent features. The natural cycle of a wetland is to convert to a land habitat as sediments accumulate. The rate at which this occurs depends on the sediment accumulation rate, the rate of precipitation (rain and other water), and changes in sea level. Since humans began using wetlands for agriculture in ancient Mesopotamia (a region in modern-day southwest Asia), they have influenced how wetlands have changed. Agriculture uses fertilizers, which add enormous concentrations of nutrients to the soil. When it rains, these fertilizers run into rivers and oceans and initiate eutrophication. Building pipelines used to transport water and dams, and draining wetlands have accelerated the destruction of wetland habitats throughout the world. This causes a loss of habitats for many animals and plants, and is a loss to the environment and people.

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Chapter 5
Ice

Arctic and Subarctic Regions

The region encircling the North Pole is called the Arctic Circle, an invisible circle of latitude (imaginary line around the Earth parallel to the equator) at 66°33' North. The arctic region sits inside the Arctic Circle and the subarctic region lies just below it. Earth's arctic and subarctic regions are extremely cold, icy areas of land and sea that receive almost no sunlight during their long, dark winters. Temperatures rarely rise above freezing. This is true even during summer in the "land of the midnight sun." The Sun's rays hit the poles at a very shallow angle and the summer sunlight—while long-lasting—is too weak to provide much heat. Arctic and subarctic regions, however, support diverse groups of land and marine (ocean) plants and animals, including humans that have learned how to survive in their harsh climates.

Water, both frozen and liquid, plays a vital role in arctic and subarctic environments. Arctic ice cools warm ocean currents and generates cold deep ocean water. Deep, cold currents flowing south from the Arctic Ocean distribute nutrients and control temperatures in the Atlantic and Pacific Oceans. The permanent covering of ice over its large area is called the Arctic ice cap. The Arctic ice cap helps to regulate Earth's temperature by reflecting sunlight. Global sea level and ocean water chemistry change when the amount of glacial ice (large masses of moving ice) on the northern continents and islands changes. The North Pole lies under a zone of dry, sinking air in the atmosphere (mass of air surrounding Earth), and the Arctic and is a windblown, frozen desert that receives very little snow each year (it almost never rains there because it is too cold).

Geography of the Arctic

A ring of continental land masses and large islands surrounds the ice-covered Arctic Ocean over the North Pole. The far northern portions of Asia (Russia, Siberia), Europe (Scandinavia) and North America (Canada, Alaska) lie within the Arctic Circle. Large islands extend even farther north: Nova Zemlya (Russia), Spitsbergen (Norway), Iceland, Greenland (Denmark), and the Queen Elizabeth Islands (Canada). Treeless plains called tundra cover the arctic and subarctic zones between the edge of cool, snowy, northern forests (boreal forests) and the coastlines of the Arctic Ocean.

Arctic ice

Sea ice covers the entire Arctic Ocean in the winter. It surrounds many of the Arctic islands and merges with glaciers and ice shelves (thick ice tht extends out from the land over water) along the edges of the continents. Huge, floating slabs of ice called pack ice crack and buckle as they constantly readjust to winds and currents. In the spring, the ice begins to melt back toward the North Pole. It breaks into large chunks of ice called icebergs and fleets of icebergs float in the open ocean. (Some icebergs, including the infamous 1912 sinker of the cruise ship *Titanic,* float south into "iceberg alley" in the North Atlantic Ocean where they are a hazard to shipping.) In the summer, the Arctic ice cap melts toward the pole. Fish, whales, and other ocean species travel north to feed and mate in nutrient-rich open waters along the Arctic coastlines.

Sea ice makes up most of the Arctic ice cap. However, glacial ice covers many of the Arctic islands, including the almost continent-sized island of Greenland. The thick ice that covers about 80% of Greenland is the last remnant of massive ice sheets that covered much of North America, Europe, and Asia during the Ice Ages of the Pleistocene era (starting 1.6 million years before the present and ending about 10,000 years ago). Ironically, Greenland is very icy and not particularly green, while neighboring Iceland is green and not particularly icy. (Warmth from Iceland's volcanoes melts ice and supports grasslands).

Life on the tundra

In spite of its harsh climate, the subarctic tundra supports a wide range of biological species. No trees grow on the tundra because a layer of frozen soil beneath the top layer of soil, called permafrost, prevents them from taking root. The tundra is also relatively dry; it receives only a few inches (centimeters) of pre-

WORDS TO KNOW

Arctic: Region of the Earth between the North Pole and the Arctic circle.

Arctic Circle: Invisible circle around the North Pole above latitude at 66°33' North.

Inuit: The native human inhabitants of the Arctic coastal regions of Eastern Asia (Siberia), North America and Greenland; also known as Eskimo, although this term has fallen out of favor.

Pack Ice: Large, floating slabs of ice.

Permafrost: Frozen layer of soil beneath the top layer of soil that has remained frozen for two or more years.

Subarctic: Region just below the Arctic Circle, to the edge of the northern forests in North America, Europe, and Asia.

Tundra: Treeless plains of the arctic and subarctic between the northern forests and the coastline of the Arctic Ocean.

cipitation (rain, snow, and any other form of water) each year. Strong winds sweep away snow and dry the soil.

The tundra has only a few year-round residents. The birds (ptarmigan) and mammals (lemmings, hares, foxes, wolves, muskoxen, polar bears, and humans) there exhibit a number of traits that allow them to survive the cold, dark winter: thick, fluffy fur or feathers that turn white in winter and brown in summer offer camouflage that insulates them from the cold; hibernating to conserve energy; and strategies for finding shelter in the snow. Some species, including lemmings, drastically reduce their population by committing mass suicide during lean times. Polar bears and humans venture onto the pack ice in winter and early spring to hunt for seals, sea lions, whales, and fish.

The tundra comes to life in late spring when the pack ice begins to retreat and the permafrost thaws. Birds and mammals travel north to join those that stayed for the winter. They feed on insects, shallow-rooted grasses and shrubs, lichens (plants that grow on bare rock), bird eggs, other animals, and especially marine life. Birds nest on the tundra. Herd animals like caribou travel north from the boreal forests of Asia, Europe, and North America to graze and bear their young. Wolves, foxes, eagles, and humans hunt the plains. In fall, when the sea ice reforms and the ground freezes solid, most of the birds and animals fly, swim, or walk south while the permanent arctic residents stock up for the long, dark, cold winter.

Permafrost

Permafrost is a soil or rock layer that has remained below freezing (32°F or 0°C) for two or more years. Frozen groundwater in the open spaces of permafrost turns layers of loose silt or sand into solid rock. Permafrost beneath the tundra in the subarctic zone is hundreds of feet (meters) thick and has been frozen for thousands of years. There are thinner, less long-lived permafrost layers beneath the northern forests of Asia, Europe, and North America and in high mountain ranges. In total, permafrost underlies about one-quarter of the land surface in the Northern Hemisphere.

In spite of its name, permafrost is not always permanent. Even slight heating can thaw portions of the permafrost. Each summer, water in the upper few feet of arctic and subarctic permafrost melts for a few months. Shallow-rooted tundra shrubs and sedges grow quickly, and produce new seeds before the winter cold refreezes the ground. Permafrost is a problem for the engineers who build roads, buildings, and pipelines in the tundra. Permafrost melts when heat from engines or furnaces escapes into the ground, and structures sink or collapse when the ground turns to soupy mud or quicksand beneath them. Scientists are concerned that a small rise in Earth's average temperature could greatly affect the arctic and subarctic environment by melting the permafrost.

Humans in the Arctic

Arctic humans, like polar bears, survive the winter by insulating themselves. in warm fur and eating fatty seal meat. Eskimo tribes of Siberia, Arctic North America, and Greenland live in snow shelters, hunt the tundra, and use boats called kayaks to fish the icy Arctic waters. Native residents of Arctic Siberia and Alaska today prefer to be called *Inuit*, which means "the people." The term Eskimo has come to represent an over-

Telephone poles rely on tripods for support in many permafrost regions. © *Joe McDonald/Corbis. Reproduced by permission.*

simplified image of Eskimos as fur-clad hunters that live in igloos instead of a diverse group of loosely-related arctic cultures that have their far-northern latitude in common.

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Glaciers

Glaciers are large masses of moving ice. Glaciers form by the accumulation of snow over tens, hundreds, and even thousands of years. Glaciers grow in cold places where more ice forms than melts each year, namely, close to the north and south poles and at high elevations (near the summits of tall mountains.)

Today, ice covers about one tenth of Earth's surface. Huge dome-shaped masses of glacial ice, called continental glaciers or ice sheets, cover the arctic island of Greenland and the most of the continent of Antarctica at the South Pole. Mountain (alpine) glaciers flow down valleys in the Himalayas, Andes, Alps and other major mountain ranges. Glacial ice affects Earth's climate, drives ocean currents (a moving mass of water that may also differ from surrounding water in properties such as temperature or amount of salt (salinity), and determines global sea level. (When more water is bound up in ice on land, sea level falls. When glaciers melt, sea level rises.) Glaciers sculpt the land beneath them as they advance and leave behind distinctive sedimentary deposits (fine soil or mineral particles) and andforms as they retreat.

How glaciers form

Glaciers form in places where more snow accumulates than melts each year, typically in climates with cold, snowy winters and cool summers. Permanent ice is common at high latitudes (imaginary lines on Earth that tell how far a place is from the equator) because the Sun's rays are less direct near the poles, and at high elevations, because air cools as it rises. Mountain glaciers grow above the snow line where it is cold enough for some snow to remain on the ground all year. The elevation of the snow line is very high near the equator, and at sea level near the poles. Glaciers cover the peaks of only few very tall mountains near the equator, including Cotopaxi in South America and Kilimanjaro in Africa, while ice flows directly into the ocean in Alaska, Siberia, Norway, and Antarctica.

Cold regions are not always snowy. Many dry, wind-blown polar areas and high mountain peaks do not have glaciers because they do not receive enough snow to outpace the melting during warm spells and wind erosion. Alpine glaciers typically form on the windward side of a mountain (the side of the mountain exposed to the wind) where where moisture-bearing winds drop heavy snows on mountain ranges. Antarctica is a frozen desert (an area with the equivalent of less than 10 inches of rain a year or about 120 inches of snow if only snow falls) that only receives a few inches of snow each year. It has remained ice-covered only because temperatures are so frigid that snow almost never melts. Once snow accumulates, it takes several years for thick, fluffy layers of loosely-packed snowflakes to compact into

WORDS TO KNOW

Alpine glacier: Mass of moving ice that is confined by mountain valleys.

Crevasse: A large crack or fissure in the surface of a glacier.

Fjord: A long, narrow, deep glacial valley flooded by the sea.

Glacial erratic: Boulders carried by glaciers and deposited away from their original location.

Glacial flour: Sediments that have been crushed and ground into a fine texture beneath a glacier.

Glacial outwash: Sand and gravel deposited by water melting from a glacier.

Glacial till: Sediments, or the rock, gravel, and sand carried and deposited by a glacier.

Ice front: The ice at the lowest end of a glacier.

Ice sheet: Very large, dome-shaped mass of glacial ice that covers a large continental area; also called continental glacier.

Kettle pond: Small round ponds that form when a melting glacier leaves chunks of ice buried in its deposits.

Moraine: A ridge formed by the unsorted gravel, sand, and rock pushed by a glacier and deposited at the outer edge, or front, of the glacier.

Snow line: The lowest elevation where snow stays on the ground or glacier surface without melting.

Two arms of a glacier encircle a mountain in Glacier Bay National Park, Alaska. *JLM Visuals. Reproduced by permission.*

thin bands of dense glacial ice. The weight of the snow on the surface packs the snow laying underneath.

How glaciers move

Glacial ice moves downhill when it has grown too thick to resist the pull of gravity (force of attraction between two objects). The steeper the slope or the thicker the ice, the faster the glacier flows. A dome of very thick ice on flat ground, like the Greenland or Antarctic ice sheet, will spread out under its own weight like pancake batter spreading on a griddle.

Glacial movement is very slow compared to other forms of moving water. (When someone says, "You are moving like a glacier!" they are usually asking you to move faster.) Some glaciers, however, are slower than others. Some glaciers cans move several hundred feet a year, others may advance or retreat on a few inches. Most glaciers flow by a combination of faster sliding and slower internal deformation (a process whereby ice shifts within the glacier itself to make the glacier appear to grow (advance) or retreat along the ground).

Like rivers, glaciers have flow patterns within them. Ice that forms from snowfall at the upper reaches of a mountain glacier moves down the valley to the ice front (end of the glacier) where it melts into streams or breaks off (calves) into the ocean. The rate at which ice flows within the glacier does not affect the position of the ice front. Glaciers grow, or advance, when more snow accumulates than melts. They shrink, or retreat, when rising temperatures or drought (long period of dry weather) cause melting to outpace accumulation. Friction slows the ice at the edges and bottom of a glacier. The fastest moving ice is along the centerline of the glaciers (an imaginary line through the center of the glacier). Ice buried deep within the glacier flows around obstacles by stretching and bending, while brittle ice at the surface breaks forming huge cracks called crevasses. Ice can stretch or bend (a process also called internal deformation, due to the weight of ice and snow above or due to melting and refreezing of ice.

Avalanche Forecasting

Avalanche! This is a winter warning that skiers, mountaineers, and backcountry travelers dread. Avalanches are snow slides. They occur when an unstable layer of snow can no longer resist the downward pull of gravity and slides rapidly down a steep slope. Avalanches can be extremely dangerous. They can tear up trees, move rocks, and bury hikers in an instant.

Scientists, wilderness park managers, and ski patrollers use their knowledge of snow science to recognize avalanche-prone slopes and to warn hikers and skiers. Several ingredients make a recipe for an avalanche, including a heavy layer of new snow, a steep slope, and a trigger (a vibration or other force that makes the snow start to move). Avalanches are common in very snowy regions, like the mountains of British Columbia and Utah. Almost all avalanches occur on 30–45° slopes that are steep enough to be unstable, but not too steep for thick snow to accumulate. Avalanche forecasters dig pits in the snow to look for unstable surfaces within the pile of snow that has accumulated during the winter. Buried ice crusts (layers of ice under new fallen snow) are particularly slippery; avalanches often follow large snowstorms that happen after short warm spells. Unstable snow layers require a trigger to detach from the snow pack and slide. A loud noise, a skier cutting across a slope, and vibrations from an explosion could all trigger an avalanche.

Glacial landscapes

Glaciers are massive earth-moving machines. Advancing glacial ice tears up rock and bulldozes it toward the ice front. Mountain glaciers carve through the solid rock that lies under the soil (bedrock) as the glaciers advance and create distinctive features. Called erosional features, these include: U-shaped valleys, hanging valleys, fjords, glacial polish and striations:

- U-shaped valley: Mountain glaciers carve narrow V-shaped stream valleys into wide, flat-bottomed U-shaped valleys. Yosemite Valley in California is a U-shaped glacial valley.
- Hanging valley: Tributary glaciers (smaller glaciers that join the main glacier from side valleys) often enter a main glacier high above the main valley floor. After the glacier melts, streams flowing from the hanging valleys form tall waterfalls.

A piece of ice hits the water as a glacier calves an iceberg. © *Ric Ergenbright/Corbis. Reproduced by permission.*

- Fjord: Unlike rivers, glaciers can erode (wear away) their valleys far below sea level. When a coastal glacier retreats, the sea fills its U-shaped valley forming a narrow, long, steep-sided bay called a fjord. Alaska, Norway, and Argentina have fjords along their rugged glacial coastlines.
- Glacial polish and striations: Sand stuck in the ice polishes the bedrock beneath the glacier, and rocks gouge out long grooves called striations.

Glacial ice is full of sediment, from huge boulders to fine specks of silt. When glaciers melt, they drop their immense load of sediment and meltwater flows from the retreating ice front. Glacial deposits and landforms cover areas that were once glaciated: glacial till, glacial flour, and outwash, moraines, erratics, and kettle ponds.

- Till, flour, and outwash: Melting glaciers deposit thick layers and mounds of unsorted sediment called till. Glacial flour is powder-fine sediment created by crushing and grinding beneath a glacier. Outwash is glacial sediment that has been carried, sorted, and deposited by meltwater streams.

- Moraine: Moraines are long, narrow mounds of glacial till. Moraines form at the ice front (end and terminal moraines), along valley edges (lateral moraines), and down the center of glacial valleys (medial moraines).
- Glacial erratic: Glaciers pluck large boulders from the ground and carry them far from their original locations before dropping them. Glacial erratics from northern Canada are strewn across the American Midwest and New England.
- Kettle pond: Glacial landscapes are dotted with small round ponds called kettle ponds that form where a retreating glacier left blocks of ice buried in its till deposits. When the blocks melt, pond water fills the round holes.

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Ice, Sea-level, and Global Climate

The amount of water frozen in Earth's ice has changed throughout the planet's history. Earth's ice budget (total ice volume) grows when the planet's average temperature falls and shrinks when it rises. During colder periods called ice ages, ice caps (large dome-shaped glaciers) extend far from the North and South Poles, and mountain glaciers (large masses of moving ice) advance into lowlands. During warmer periods, ice retreats back toward the poles and up mountain valleys. Earth has even been completely ice-free several times during its long history.

Earth's water budget, the total amount of water on the planet, does not change over time. When more water freezes into ice on land, there is less water in the oceans, so global sea level falls during ice ages. Shorelines move seaward, and the edges of the continents are exposed above sea level. When polar ice caps and mountain glaciers melt, more water is stored in the oceans, and global sea level rises. Shorelines move landward and coastal regions are submerged below sea level. (Ice floating in the ocean does not affect global sea level when it melts or forms because no water is added or removed.)

Global warming and cooling

Energy from the Sun ultimately determines Earth's average temperature and thus, its ice budget. The planet warms and cools as its position changes relative to the Sun and it receives more and less sunlight over time. The shape of Earth's orbit (the path it revolves around other objects), the tilt of the planet as it spins in its orbits, and the intensity of its seasons all change in repeating patterns over thousands of years. Glacial advances and retreats in the past have matched the timing of these astronomical cycles with global warming and cooling. (They are called Milankovitch cycles after the Serbian mathematician who developed the theory relating Earth motions and long-term climate change.)

Global warming and cooling also occur in response to changes on Earth's surface and in its atmosphere (mass of air surrounding Earth). Gases like carbon dioxide and water vapor keep Earth warm by allowing incoming sunlight to pass and then trapping escaping heat. The layer of insulating gases in the atmosphere is called the greenhouse layer because it works like glass in a garden greenhouse. Without it, Earth would be a frigid, icy planet that could not support biological life. Processes like forest growth lead to green plants that take in the greenhouse gas carbon dioxide and release oxygen. The removal of greenhouse gases from the atmosphere leads to global cooling, advance of glaciers, and sea level fall. When more greenhouse gases escape into the atmosphere, Earth warms, ice melts, and sea level rises.

Ice ages and sea level lows

Massive ice sheets (flat layers of fresh water ice covering extensive regions of the world advanced and retreated across northern Europe, Asia, and North America many times during the ice ages of the Pleistocene Epoch (a division of geologic time that lasted from 2 million to 10,000 years ago). Canada and the northern portion of the United States are strewn with evidence of the last Pleistocene ice sheet in North America. The

WORDS TO KNOW

Cretaceous period: A division of geologic time from 144 to 65 million years ago; along with the Jurassic, and Triassic, this period comprised the Mesozoic Era known as "the age of the dinosaurs."

Glacier: Large mass of moving ice.

Greenhouse layer: Layer of gases in the atmosphere that lets pass incoming solar rays and traps escaping heat.

Ice budget: The total amount of frozen water on Earth.

Ice sheet: Very large, dome-shaped mass of glacial ice that covers a large continental area; also called continental glacier

Land bridge: Strip of dry land that connects islands or continents when it is exposed by lowered sea level during glacial periods.

Milankovitch cycles: Predictable changes in Earth's average temperature that are caused by changes in Earth's position relative to the Sun.

Pleistocene Epoch: Division of geologic time from 2 million to 10,000 years ago; also known as the Ice Age.

Collapse of the Larsen B Ice Shelf

A Rhode Island–sized piece of one of Antarctica's floating ice shelves broke into a fleet of thousands of icebergs over a few weeks in early 2002. Ice shelves are the floating edges of continental glaciers that form where a glacier flows out over the sea. The shelves that cover most of Antarctica's coastal inlets (narrow strip of water running into the land or between islands) and bays are the outlets of faster movements of ice called ice streams that drain ice from the interior of the ice sheets.

The breakup of the relatively small ice shelf, called Larsen B, in a bay along the eastern edge of the Antarctic Peninsula did not, in itself, cause global sea level rise or signal an impending crisis. Ice shelves are already floating in the water, so sea level does not rise when they break up. Ice melts and breaks off into the sea at the front of all glaciers, even advancing ones. Furthermore, a limited local climate change caused the demise of the Larsen B shelf, and there is no evidence that the event had anything to do with human-caused global warming.

The breakup of the Larsen B shelf did, however, cause concern among scientists for a number of reasons. First, the shelf has been losing ice more rapidly than new ice has been accumulating on the glaciers that feed it. This is true of many of Antarctica's ice shelves, including the very large ones that float in the Weddell and Ross Seas at the outlets of ice streams in the West Antarctic ice sheet. It indicates that the Antarctic ice sheets are indeed melting into the ocean. Second, the ice streams that feed the Larsen ice shelf all sped up immediately after the breakup. Apparently, the mass of floating ice acts as a buttress that slows the ice streams. Once a shelf collapses, ice flows rapidly into the ocean. If a very large shelf like the Ross Ice Shelf in west Antarctica were to collapse, it could potentially trigger a rapid rise in global sea level. Third, the Larsen B's breakup and dramatic increase in rate of ice loss followed a very minor local temperature increase (about 4.5°F (2.5°C) in its last 65 years). So, small climate changes can have large consequences.

advancing ice polished, etched, and carved the solid rock layers of northern Canada. It tore rock from the ground and carried it south. When the ice melted, it stranded boulders and dropped piles of Canadian sediment (sand, grain, or silt) across the American Midwest and New England.

The last North American ice sheet was miles (kilometers) thick and reached as far south as Long Island, New York. Like an overloaded ship, the continent sank under the weight of the ice. The Great Lakes are meltwater-filled depressions created by the ice sheet, and the coastlines of New England and eastern Canada have been rising out of the sea since the ice melted away.

When the last Pleistocene glaciers reached their maximum extent about 20,000 years ago, ice covered about 30% of the Earth surface. Global sea level was about 350 feet (107 meters) lower than its present-day level. Rivers flowed across exposed

Scientists explore an ice cave on the Larsen ice shelf. © *Galen Rowell/Corbis. Reproduced by permission.*

continental shelves (gently sloping shallow seabed extending into the ocean from a continent) to shorelines far seaward of their present locations. Land animals lived on regions that are submerged below sea level today, and migrated between islands and continents on exposed land bridges. Land bridges are strips of dry land that connects islands or continents. Some of North America's first human inhabitants arrived via a land bridge between Siberia and Alaska.

Global warming and sea level highs

Earth was almost (if not completely) ice-free about 100 million years ago during the Cretaceous period of geologic time (this period lasted from 144 to 65 million years ago). High mountains and continental areas that were over the poles bear no trace of deposits from glaciers. Geologists (Earth scientists) have even found fossils of tropical plants that resemble palm trees in rocks that formed near the poles. Sea level was much higher in the Cretaceous period than it is today. Only central highlands of the continents remained exposed. A shallow seaway covered the interior of North America.

Humans and global climate change

Today, Earth is in a period that is moving away from the "ice-house" conditions of the Pleistocene. Global temperature and sea level have been rising and ice has been melting since the last glacial maximum. Ice now covers only about 10% of Earth's surface. Most continental ice is bound up in the massive ice sheets covering the continent of Antarctica at the South Pole. Small mountain glaciers and the ice sheet covering Greenland are all that remain of the massive Pleistocene ice sheets of the northern hemisphere. Much of Earth's continental ice cover is presently retreating, including the Greenland ice sheet, the West Antarctic ice sheet, and many mountain glaciers. The melting is probably adding to a rise in sea level of a few inches per century.

Scientists and environmentalists are concerned that humans are contributing to naturally-occurring global warming by releasing greenhouse gases into the atmosphere. Burning fuels like wood, coal, oil, and natural gas releases carbon dioxide, and scientists agree that booming human population growth and industrialization over the last century have significantly raised the level of carbon dioxide in the atmosphere. Most researchers also accept the conclusion that the additional carbon dioxide will have some effect on Earth's climate.

Scientists do not, however, agree on what the effects of adding carbon dioxide and other gases to the atmosphere will be in the future. Some argue that enhanced greenhouse warming could lead to rapid sea level rise and dramatic global climate change that would threaten human property, food supplies, and even lives. Others predict that the additional greenhouse gases may have little effect, and that slow, steady warming will continue at a rate that allows humans to gradually adjust. There are also climate scientists who theorize that upsetting the balance of greenhouse gases, ice cover, and sea levels could trigger the start of a new ice age.

The question of human-caused greenhouse warming is one of the most pressing and controversial environmental issues of our time. Scientists are working to understand the complex nature of Earth's past and present climate in hopes of predicting changes in the future. Policy makers, environmentalists, and business leaders hope to use scientists' predictions and recommendations to design workable solutions.

Laurie Duncan, Ph.D.

WORDS TO KNOW

Antarctic ice cap: Ice covering the continent of Antarctic and Southern Ocean region around the South Pole.

Arctic ice cap: Ice covering the Arctic ocean and land areas north of the Arctic Circle in the North Pole.

Continental glacier: Very large, dome-shaped mass of glacial ice that completely covers the terrain beneath it; also called ice sheet.

Glacier: Large masses of moving ice.

Iceberg: Block of floating freshwater ice that has broken from a glacier.

Ice cap: Ice at the poles; large dome-shaped glaciers that are smaller than ice sheets.

Ice sheet: Very large, dome-shaped mass of glacial ice that completely covers the terrain beneath it; also called continental glacier.

Ice shelf: A floating platform of ice where an ice sheet flows out over water.

Ice stream: Portion of a glacier or ice sheet that flows faster than the surrounding ice.

Sea ice: Frozen seawater floating on the ocean surface.

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Polar Ice Caps

Ice covers Earth's North and South Poles. Weak sunlight and long, dark winters at high latitudes (imaginary lines on Earth that tell how far north or south a place is from the equator) create frigid conditions that support the formation of year-round glaciers (large masses of moving ice) on land and seasonal ice in the oceans. An ice cap is a permanent covering of ice over a large area. The arctic ice cap at the North Pole includes sea ice floating in the Arctic Ocean; glaciers in northern Asia, Europe, North America; and sheets of ice on the island of Greenland. The ice cap at the South Pole is made up of the massive Antarctic ice covering and ice in the Southern Ocean.

Polar ice caps play a vital role in regulating global climate, temperature, ocean currents, and sea level. They keep nutrient-rich waters of the Arctic and Southern Oceans at a livable temperature for rich communities of biological life. A total of 99.997% of Earth's fresh water is bound up in polar ice. Humans have lived in the North Pole area, the Arctic, for thousands of years and navigators have long been challenged by ice that blocks shipping and travel routes. Humans discovered the South Pole region, Antarctica, in the early 1800s. With the exception of explorers, scientists, and tourists, it remains uninhabited by humans today.

Ice sheets

Most of Earth's ice is bound up in immense ice sheets that cover the southern continent of Antarctica and the large arctic island of Greenland. Ice sheets, also called continental glaciers,

Flags mark the ceremonial South Pole, while the true South Pole is visible in the distance. *© Galen Rowell/Corbis. Reproduced by permission.*

are dome-shaped masses of ice that completely cover the underlying landscape. Ice sheets are huge; they cover areas larger than 31,069 square miles (50,000 square kilometers), about the size of Switzerland. They have thick portions called domes where snow accumulates. Ice sheets move when the dome spreads out and eventually compacts into thin, dense layers of ice. Continental glaciers can spread across flat ground because the weight of the thickest ice pushes their edges outward. (Imagine a blob of honey spreading on a slice of flat toast.)

All but a tiny portion of the frigid continent of Antarctica. (Antarctica is about 1.5 times the size of the United States. It is roughly circular in shape and the South Pole lies near its center.) Antarctica lies under a region of very dry air in the atmosphere (air surrounding Earth), and its wind-blown interior plains are Earth's largest deserts (Antarctica receives only a few inches of precipitation per year in the form of snow). Each year, only a few inches (centimeters) of new snow accumulate on the Antarctic ice sheet. It has taken hundreds of thousands of years for thin layers of snow to compact into thousands of feet (meters) of glacial ice.

A range of tall mountains, called the Trans-Antarctic mountains, divides Antarctica and its overlying ice sheet into two geographic regions. The larger piece, East Antarctica, is a single continental block covered by a slow-moving, stable ice sheet with an average depth of more than 1.5 miles (2.4 kilometers)! West Antarctic is composed of numerous small continental blocks, sediment-filled basins (basins filled with sand, grain, or silt), and even several volcanoes. The West Antarctic ice sheet

Endurance: The Shackleton Expedition

The legendary polar explorer Sir Ernest Shackleton (1874–1922) sailed for Antarctica aboard the ship *Endurance* with a crew of 27 men. Norwegian explorer Roald Amundsen (1872–1928) had beaten him to the South Pole several years earlier, and he hoped to even the score by becoming the first to cross the icy southern continent on foot. Shackleton and his men left England on August 8, 1914, four days after Britain declared war on Germany. They would become the players in one of the most dramatic stories of human suffering, heroism, and survival of all time.

Shackleton's plan was to sail *Endurance* as far inland as possible through a large bay called the Weddell Sea, and then continue on foot across Antarctica. *Endurance* and her crew arrived on time for summer in Weddell Sea in November 1914. Shackleton knew that he needed to find a clear passage among the slabs of sea ice and towering icebergs and make landfall before April when thick winter ice covers the entire sea.

He didn't make it. *Endurance* froze into the ice in December 1914. Shackleton and his men spent the cold, dark Antarctic winter living aboard and around their iced-in ship. Their luck soured further when buckling ice crushed the *Endurance.* The ship sank in November 1915, and Shackleton's expedition was stranded on the ice. They drifted north on a slab of sea ice for another four months, living on their dwindling provisions, seal meat, and eventually their dogs.

They had been on the ice for a year and a half when the slab of ice they were floating on finally disintegrated. To make matters worse, they had floated clockwise around the Weddell Sea and out into the ferocious waters of the Southern Ocean. Shackleton loaded his weary, starving men into *Endurance's* life boats, and they managed to land on bleak, wind-buffeted Elephant Island. Knowing that they would probably not survive the winter there, Shackleton set out with five men to find rescue. They rowed hundreds of miles across the world's most treacherous waters in tiny, open lifeboats. Miraculously, and somewhat ironically, they arrived at the very whaling station that they had departed from almost two years earlier. The men who stayed behind on Elephant Island had given up all hope of survival when Shackleton himself arrived to rescue them on August 30, 1916. Thanks to Shackleton's extraordinary courage and leadership, all 27 men survived the expedition.

has many faster-moving portions called ice streams that slide over a slippery layer of sediment and water. Ice streams drain ice from central domes toward the coast where they flow out over the ocean to form floating platforms of ice, called ice shelves. Scientists are concerned that the West Antarctic ice sheet is melting faster than it is growing. Ice cools the climate by reflecting the heat energy from the Sun back towards space. A significant reduction in ice, therefore, would lead to warmer temperatures in the region.

The world's second largest ice sheet covers the far northern island of Greenland. The Greenland ice sheet is the last remnant of the ice sheets that covered much of the northern hemisphere during the numerous Pleistocene (2 million–10,000 years ago) ice ages. Like the West Antarctic ice sheet, the thick ice on Greenland appears to be melting more rapidly than it is growing.

During the 1915 British Imperial Trans-Antarctic Expedition, Sir Edmund Shackleton's boat *Endurance* sinks in the pack ice of the Weddell Sea while sled dogs sit and watch. *© Underwood & Underwood/Corbis. Reproduced by permission.*

Ice shelves

Ice shelves form where the protruding edges of ice sheets extend over the ocean. Ice shelves grow when more ice accumulates on the ice sheet, and shrink by melting and breaking off icebergs into the ocean. Icebergs are the splintered chunks of ice shelves. Ice shelves cover the coastal bays and inlets (narrow strips of water running into the land or between islands) of Antarctica. The fast-flowing ice streams of the West Antarctic ice sheet produce ice shelves over two very large Antarctic bays called the Ross Sea and the Weddell Sea.

Sea ice

Sea ice is frozen sea water that makes up a large portion of the polar ice caps. (Ice shelves and icebergs are not considered sea ice because they are composed of fresh water.) Sea ice is seasonal; it forms in winter and melts in summer. Huge slabs of saltwater ice continuously crack and buckle as they move with ocean currents (a steady flow of ocean water in a prevailing direction) in the Arctic and Southern Oceans. The mass of sea ice in the Arctic Ocean extends to the northern edges of North America, Asia, and Europe during the winter months, and melts back toward the North Pole in the summer. Antarctica is surrounded by a halo of sea ice that extends far north into the Southern Ocean in winter and melts almost completely away in summer.

Sea ice does not affect global sea level because it is already floating in the ocean. It is, however, extremely important to the climate and biology of polar regions. Many animals in the Arctic (polar bears, seals, and whales) and Antarctic (penguins, whales, seals, sea lions) depend completely on seasonal sea ice for their habitat. The amount of sea ice varies from year to year, affecting ocean temperatures and currents worldwide.

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Chapter 6
Water, Weather, and Climates

Climate

Global climate is the long-term pattern of temperature and precipitation on Earth's surface. Heat and water are unevenly distributed around the globe, and Earth has many climate zones (areas with a characteristic climate) and subclimates (areas with unique climate features within a climate zone) with unique patterns of temperature, rainfall, winds, and ocean currents (the circulation of ocean waters that produce a steady flow of water in a prevailing direction). Climate zones support communities of plants and animals (ecosystems) that have adapted to thrive there. The term climate refers to temperature and moisture patterns that characterize a large region over tens, hundreds, or even thousands of years. Local changes that last days, weeks, or seasons, like storms and droughts, are called weather.

Regulating sunlight: the ozone and greenhouse layers

Energy from the Sun drives Earth's climate and biology. Sunlight heats the surface and nourishes plants that, in turn, feed animals. Heat drives ocean currents, winds, and the hydrologic cycle (the circulation of water between the land, oceans, and the layer of air surrounding Earth, called the atmosphere). Layers of gas in the atmosphere regulate incoming solar energy and maintain the planet's average temperature at about 60°F (16°C). The gaseous layers keep Earth within the temperature range where life-sustaining oceans are liquid and life flourishes.

Unfiltered sunlight is too strong for organisms; it damages plants and burns animal tissues. A layer of ozone gas in the outer atmosphere acts as a shield that protects Earth from the

WORDS TO KNOW

Boreal forests: Treed areas of the northern temperate regions of North America, Europe and Asia that are dominated by evergreen trees like firs, pines and spruces.

Climate effect: Temperature and moisture patterns that characterize a large region over tens, hundreds, or even thousands of years.

Boys play hockey on a frozen part of Lake Baikal which they have cleared of snow. © *Dean Conger/Corbis. Reproduced by permission.*

Sun's most dangerous rays—ultraviolet radiation. Ozone absorbs most of the Sun's ultraviolet rays. The filtered sunlight that reaches the surface has the correct intensity to set off a process in green plants in which they produce their own food. When sunlight strikes objects on Earth's surface, they warm up and radiate heat back toward outer space. Gases like carbon dioxide and water vapor keep Earth warm by trapping heat in the lower atmosphere. They are called greenhouse gases because they warm Earth's surface the same way a greenhouse stays warm in the winter.

WORDS TO KNOW

Climate zone: Areas of the world with a characteristic climate. Climate zones are described as arid, Mediterranean, mountain, polar, temperate, and tropical.

Global warming: Increase in the average temperature of the Earth's surface.

Ocean currents: The circulation of ocean waters that produce a steady flow of water in a prevailing direction.

Ozone layer: Region in the outer atmosphere that absorbs the Sun's harmful ultraviolet radiation.

Rainshadow: An area that has decreased precipitation because a barrier mountain range causes prevailing winds to lose their moisture before reaching it.

How climate works

Sunlight falls unevenly on Earth's surface. The Sun's rays are more direct at the equator and less direct at the North and South Poles, causing surface temperature to decrease the farther away the area is from the equator. Temperature also decreases with altitude (elevation), making it very cold on high mountain peaks. This uneven heating creates heat-driven flows in the oceans (currents) and atmosphere (winds). Circular patterns of rising warm air and sinking cool air in the atmosphere (called Hadley cells) control the distribution of rainfall. Six Hadley cells, three in each hemisphere (half of the Earth), create wind belts (consistent winds in a prevailing direction) and climate zones.

To illustrate, follow a volume of air as it completes a trip around the Hadley cell north of the equator: Intense sunlight heats ocean water in the tropical zone around the equator. The air warms, and gains moisture from the warm water below it. It rises and flows north of the equator, cooling as it moves. Because cool air holds less moisture than warm air, the water vapor condenses (changes to liquid from a gas) into clouds and falls as heavy rain in the tropics. Once dry, the air flows north and sinks over one of the hot, dry deserts north of the tropics like the Sahara. The dry air then flows back along the surface toward the equator. Earth's eastward rotation causes the returning winds to bend toward the west; they are the strong, steady Trade Winds that blow on either side of the equator.

Climate zones

Earth's climate zones are defined by their average yearly rainfall (or snowfall) and temperature. In general, they are alternating, east-west oriented, wet and dry zones under the rising and falling Hadley cells. If Earth were a simple, water-covered ball, without complicating factors like continents, high mountain ranges, and ocean currents, there would be five climate zones in each hemisphere: tropical, arid, temperate, cold, and polar.

A man pedals his bicycle along a flooded Manila road, August 23, 2001. Heavy monsoon rains caused massive flooding in the Philippine capital. *© Reuters/Corbis. Reproduced by permission.*

- Tropical (hot, wet): Lush, biologically-diverse rainforests thrive in the tropical zone at the equator. The jungles of central Africa, the Amazon basin in South America, and south Pacific Islands like Borneo lie in the tropical zone.
- Subtropical arid and semi-arid (hot, dry): Earth's great deserts lie in arid zones north (Saharan, Arabian) and south (Kalahari, Australian Outback) of the equator. Dry, semi-arid (mostly arid) grasslands form the bordering lands around the subtropical deserts. The African savannah, Asian steppe, and Great Plains of North America are semi-arid grasslands that support large mammals like elephants, horses, and buffalo.
- Temperate (mild temperatures, moderate rainfall): A large percentage of Earth's population lives in mild and temperate regions of North and South America, Europe, and Asia. These climates often have warm, dry summers and cool, wet winters. Coastal regions are usually wetter and have less extreme temperature variations than inland temperate regions.
- Cold (cold, moderate rainfall): The cold, snowy, northern forests of North America, Scandinavia, and Asia are called the boreal zone. The treeless plain of the sub-arctic between the boreal forest and the polar ice cap (the thick covering of permanent ice and snow at the North and South Poles) is called tundra.
- Polar (very cold, very dry): The North and South Poles are cold, dry deserts. The polar ice caps have formed from the accumulation of light snows over thousands of years.

The positions of continental land masses, ocean currents, and high mountain ranges also affect the pattern of climate zones. Land heats up and cools down faster than water. Many coastal areas have climates affected by wet onshore winds that bring rain, dry offshore winds that create coastal deserts, or reversing winds (monsoons) that cause alternating wet and dry

WORDS TO KNOW

Temperate zone: Region characterized by moderate temperatures, rainfall, and weather and overall climate that is neither hot nor cold, wet nor dry.

Tropics: Band of hot, rainy climate that lies north and south of the equator.

Tundra: Treeless area between the Arctic ice cap northern boreal forests that has permanently frozen soil layers called permafrost.

Santa Ana Winds

The Santa Anas are hot, dry air winds that blow from the northeast down the canyons of Southern California. Southern California has a Mediterranean climate. Like the residents of the Mediterranean coast of Europe, southern Californians enjoy extremely pleasant year-round weather. Sunshine is the norm. Balmy onshore winds bring moisture to citrus, olive, avocado, and palm trees that flourish even though it rarely rains. The dry heat and blustery gusts that accompany the Santa Anas are particularly unpleasant for laid-back southern Californians.

Santa Anas usually appear during Fall when a low pressure system of cold air forms over the desert and mountains to the northeast. Because cool air sinks, the air mass moves down toward the coast of Southern California. It warms as it falls, but stays dry. It speeds up as it descends through the canyons and emerges as strong, hot offshore breeze that lasts for a few weeks before abating. Other coastlines experience similar winds, including the Mistral in the Mediterranean and Papagayo in Central America.

The Santa Anas cause a great deal of actual damage. They dry out the coastal vegetation and, once brush fires have ignited, they fan and spread the flames. Because of residential development in the canyons and mountain foothills of southern California, recent Santa Ana fires have threatened many lives and property.

seasons. Warm ocean currents keep some regions that are far from the equator warm, and cold water upwelling (rising up) from the deep ocean cools some tropical coastlines and islands.

Winds that flow from the oceans onto land generally lose their moisture as they travel inland or uphill. The interiors of large continents like Asia, Australia, and North America are generally dry. When moist air reaches a tall mountain range, it drops rain as it rises and cools. The slopes of mountain ranges exposed to the wind are typically wetter than the sides away from the wind. Arid deserts and semiarid grasslands form in the rainshadows (an area of decreased precipitation on the downwind side of a mountain), behind tall mountains. In the United States, high winds called the jet stream carry moisture-rich air from west to east. It is rainy in the Pacific Northwest, and snowy on the western slopes of the Cascade, Sierra Nevada, and Rocky Mountains. The air is bone dry when it reaches the Mojave, Sonoran, and Chihuahuan deserts of the American Southwest, and northern Mexico.

Climate change

Changes in the factors that determine climate can lead to global climate change over time. Cooling leads to global sea level fall and glacial advance (increased ice formation and spread of ice at the polar ice caps); warming melts the polar ice caps and water rises to cover the edges of the continents. In either case, Earth's climate zones and regional subclimates must adjust to the new temperature and rainfall patterns. Geologic data confirms that Earth has warmed and cooled throughout its history as its position has changed relative to the Sun. Plate tectonic forces (the bumping together and moving apart of large plates of Earth's crust) have rearranged the continents, changing the paths of ocean currents and the pattern of dry land, bodies of water, and ice. The amounts of greenhouse gases and ozone in the atmosphere have changed naturally and because of human activities. Global warming is the increase in the average temperature of the Earth's surface. Many scientists and environmentalists are concerned that increased carbon dioxide in the atmosphere from the use of fossil fuels like oil and coal could lead to global warming and climate change.

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Clouds

Clouds are made of very small drops of water of water, ice crystals, and other small particles in the atmosphere (mass of air surrounding Earth). The water comes from condensation, a process that allows small drops of water to form as the air cools. Cloud shapes and the way clouds form give scientists important clues about local weather and conditions in the atmosphere around the world.

Clouds are divided into several types or families of clouds. These families of clouds are named according to where or how they form, and include high-level clouds, middle-level clouds, and low-level clouds. In addition to belonging to a family, clouds are also named for their shape. Puffy clouds are known

Clouds are formed from water in the atmosphere. © *Joseph Sohm, ChromoSohm Inc./Corbis. Reproduced by permission.*

WORDS TO KNOW

Condensation: The transformation (phase change) of a gas to a liquid.

Precipitation: Transfer of water as rain, slow, sleet, or hail from the atmosphere to the land or ocean surface.

as cumuliform clouds, and flat sheet-like clouds are known as stratoform clouds.

How clouds form

In general, as warm, moist air rises upward through the atmosphere, the air cools. As the air cools, ice crystals or water drops appear and clouds form. Meteorologists (scientists who study weather and climate) name clouds based on how they form, where they form, and the shape of clouds. Cloud classifications are organized into groups or families.

Families and types of clouds

The altitudes (heights above the ground) used to describe cloud families change and become lower as one moves from the equator toward the North or South pole. As one moves north or south from Earth's equator (imaginary circle around Earth between the North and South Pole), high altitude family clouds can be observed at much lower altitudes.

High level clouds include cirrus, cirrostratus, and cirrocumulus clouds. These clouds are found at altitudes between 16,000 and 45,000 feet (4,877 and 13,716 meters) above the ground. In comparison, a jumbo passenger jet usually cruises at about 36,000 feet (10,973 meters) above the ground.

Middle level clouds include altostratus, altocumulus, and nimbostratus clouds, and are found between 6,500 and 22,000 feet (1,981 and 6,706 meters) above the ground. These clouds include include altostratus, altocumulus, and nimbostratus clouds. As with many cloud families, the altitudes are not exact, and they can vary depending on the type of terrain (sea or mountains) over which the clouds form or travel.

Low-level clouds include stratus and stratocumulus clouds that are found below 6,000 feet (1,829 meters).

Clouds that form rapidly in a vertical (up and down) direction are known as vertical development clouds. Vertical development clouds include cumulus and cumulonimbus clouds, which are the clouds that form a thunderstorm. Vertical development clouds form rapidly as air rises from the Earth's surface. They are found anywhere from the surface of the ground to 45,000 feet (13,716 meters). In some very strong thunderstorms, the clouds may reach even higher. One factor that contributes to the development of thunderstorms is unstable warm and humid air that quickly rises through the atmosphere to great heights where the surrounding air is very cold.

Shape and color of clouds

The shape of a cloud is determined by the manner in which the water drops condense and the forces of winds that can act to tear away pieces of the cloud as it builds and moves in the atmosphere.

Whether a cloud is light or dark depends upon how much light can pass through the cloud. Water droplets bend or block light. Thicker clouds block more light than thinner clouds, and so appear darker than thinner clouds.

Names of clouds

When clouds are widely separated from other members of their family, the term *fracto* is added to their name. When a cloud produces rain (precipitates) it is also called a nimbus cloud and the term *nimbus* is added to the cloud name.

High clouds Cirrus clouds occur at high levels and are usually wispy and long.

If air rises directly upward through the atmosphere, the air cools very quickly. As the air cools, ice crystals or water drops appear and cumulus clouds form. Cumulus clouds are billowy, puffy clouds that resemble cotton balls.

Stratus clouds look as if they are blankets or layers of clouds.

Because it is very cold at high altitudes, high clouds including cirrus clouds, cirrostratus clouds, and cirrocumulus clouds are composed of ice crystals. Particles of dust or pollution

Ice in the Air, Pilots Beware!

Water in the atmosphere can present special dangers to aircraft. For this reason the ability to identify cloud types is an important skill for pilots. In addition, special weather forecasts prepared by aviation meteorologists (scientists who study weather) help pilots avoid dangerous conditions.

When water droplets hit the cold surface of airplanes, ice can form. Ice that forms on wings changes the shape of the wing and can lower or destroy the ability of a wing to produce lift, the force that acts against gravity to allow an airplane to fly.

Ice can also change the shape of key parts of an airplane that allow pilots to control whether the aircraft goes up or down (the elevators), turns left or right (the ailerons), whether the nose moves left or right (the rudder), or the aircraft flies at slower speeds when taking off or landing (the flaps). In every case, ice changes the shape of the surface of these controls and can thus, interfere with a pilot's ability to control aircraft.

Flying through clouds can also be an interesting experience, and not all clouds are dangerous. If the weather is warm enough, and the altitude low enough, the danger of ice forming on the aircraft is low. In addition, there are different types of ice (smooth, rough). Some small amount of frost are normal and not dangerous. Before flight, chemicals are regularly used to remove ice and to help keep ice from forming on airplanes. During flight, special heaters are regularly used to help keep ice from forming on sensitive instruments and parts of airplanes.

often form the center around which the ice crystals grow. For this reason, dust or particles of pollution are often called centers of crystallization if ice grows around them, or condensation nuclei (nuclei meaning the center) if water drops form around them.

Cirrus clouds often produce a shape that looks like a horse tail. These "mares' tails" are wisps of ice crystals. Cirrostratus clouds, because they are thin and because their ice crystals act to both reflect and bend sunlight, sometime appear to form a circle or halo around the Sun or Moon.

Cirrocumulus clouds often appear as patch-like thin clouds.

Middle level clouds Middle level clouds include altostratus clouds, altocumulus clouds, and nimbostratus clouds. These clouds are composed of water drops with some ice crystals near the top of the clouds.

Sometimes both middle level and low level clouds contain water that is still in liquid water drops even though the air around them is well below the freezing temperature. This super-cooled water (water below freezing that has not yet formed an ice crystal) needs only a seed, usually a particle of dust or pollution around which to form ice.

At one time, scientists experimented with making rain by seeding clouds with a chemical called silver iodide. It was hoped that the silver iodide would provide a center around which large water droplets would form. When the water droplets grew large enough, they would fall as rain. Cloud seeding thus offered hope that it might be possible to produce rain in dry regions. The results of these early experiments were disappointing, however, and produced little rain beyond the amounts that fell without cloud seeding.

A tower of the Golden Gate Bridge rises above the fog covering San Francisco Bay. *© Morton Beebe/Corbis. Reproduced by permission.*

Because of the way ice crystals reflect and deflect light, altostratus clouds often present a bluish-layered appearance. Depending on thickness, altocumulus clouds often have white or gray layers that appear in washboard or wave-like formations. Warm moist air that rises can also result in the formation of castle-like altocumulus castellanus clouds, a form of altocumulus that often appear as isolated cumulous clouds with billowing tops.

Another form of altocumulus cloud is called a standing cloud (properly termed a lenticular altocumulus cloud), and is formed by condensation in currents of air that cool as they move upwards to cross mountains and ridges. Although constantly forming and disappearing, the standing lenticular altocumulus cloud formations appear not to change and thus seem to stand over the mountain or ridge lifting the air.

Nimbostratus clouds often appear as heavy, gray, moisture-laden cloud layers.

Low level clouds Low-level stratus clouds are the gray clouds that often produce rain and some types of fog.

Stratocumulus clouds present the familiar, cotton ball-like cumulus shapes in an elongate form (a cumulus shape drawn out by shearing winds).

Clouds that pass through many levels of the atmosphere, the cumulus and cumulonimbus clouds, often have a widely varying mixture of ice and water. These clouds often have swirling currents of air that move upwards and downwards. These rapid updrafts and downdrafts of air allow ice crystals to appear at much lower levels than normal. As they cycle through the cloud, the ice crystals can grow large enough to fall to the ground as hail.

Although formed from air rising upward from the ground and lower levels of the atmosphere, cumulus clouds often form in fair weather and do not form violent updraft or downdraft currents of air. These cumulus clouds have flat bases and curved tops that look like domes of buildings.

When strong and violent updrafts and downdrafts of air form, however, the air is said to be unstable and the cumulus clouds are said to be more developed. These cumulus clouds have mushroom or cauliflower-like tops, and they often produce rain.

When cycles of air moving upwards and downwards become very violent, cumulonimbus clouds form. Cumulonimbus clouds are dark clouds with anvil-like tops (very flat tops with trailing clouds spreading out like a tabletop) that are often cut off (sheared) by strong winds in the upper atmosphere. Cumulonimbus clouds often have heavy turbulence (rough and violent disturbances of air), rains, lightning, and thunder. The most unstable and violent cumulonimbus clouds can occur in cells or groups capable of forming tornadoes.

K. Lee Lerner

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Monsoon

A monsoon is a regional wind that reverses directions seasonally. In southern Asia, wet, hot monsoon winds blow from the southwest during the summer months and bring heavy rains to a large area that includes India, Bangladesh, Sri Lanka, Pakistan, and Nepal. Northeasterly winds (winds are named by the direction from which they blow) that blow down from the Himalaya Mountains in the winter are cool and dry. Monsoon winds occur in many regions around the world, in Africa, Australia, and in North America, where the Mexican monsoon brings over half of the year's total rain to Northern Mexico, Arizona, and New Mexico each June through August. The Mexican monsoon is a smaller version of the classic and well-known southern Asian monsoon.

The word monsoon comes from the Arabic word *mausim* which means "season." In southern Asia, the monsoon controls the seasons: hot and wet in the summer, cool and dry in the winter. Plants and animals of southern Asia have adapted ways to survive the annual cycles of flood and drought (prolonged period of dry weather). Humans depend on the rains to fill storage reservoirs and to water crops, especially water-intensive staples like rice and cotton.

How monsoons work

The Asian monsoon works like a large version of reversing land-sea breezes along coastlines. Water heats and cools more slowly than dry land. On a sunny day at the beach, the air over land heats more quickly than air over the water. Warmer air expands and rises. Cool air moves in from the ocean to replace the rising warm air, and this movement creates a nonshore breeze. When the sun goes down in the evening, the land cools more quickly than the sea, and the wind changes direction.

The Indian peninsula is a piece of low land surrounded on three sides by the waters of the northern Indian Ocean; it separates the Arabian Sea from the Bay of Bengal. The massive Himalaya Mountains to the north isolate it from winds and weather in the rest of Asia. India lies just north of the equator, so it receives very intense sunlight and heats up beginning in April. When the hot air over the peninsula rises, wet air from

WORDS TO KNOW

Ganges and Brahmaputra Rivers: Rivers of northern India and Bangladesh that carry water from the Himalayas into the Bay of Bengal. The rivers are sacred in Hindu religion.

Himalaya Mountains: Tall mountain range in central Asia that includes nine of the world's ten highest peaks, including the tallest one, Mt. Everest.

A rickshaw puller drags his vehicle through a flooded street in the eastern Indian city of Calcutta, India. *© Reuters/Corbis. Reproduced by permission.*

the tropical Indian Ocean flows onshore to take its place. The wind flows from the southeast, across India and into the Himalayan foothills where it is forced upward. Warm air holds more moisture than cool air. The moist ocean air blown in by these winds cools and condenses (changes into liquid from a gas) as it rises, resulting in heavy rains. Monsoon rains are often hard, sustaining rains.

The rainy season

The "season of the peacock" begins in mid-May as the monsoon wet phase reaches southern India. Peacocks are the symbol of life-giving rains in India. Male peacocks begin courting females by flashing their brilliant tail feathers a few weeks before clouds form and the arrival of downpours that transform the parched, brown landscape to a lush, green paradise. As the rainy season progresses, two arms of wet weather extend across the region: one reaches up from the tear-drop-shaped island of Sri Lanka (formerly Ceylon), to the tip of India, and toward Pakistan; the other comes in from the Bay of Bengal and Bangladesh, and crosses central and northern India. By early July, the two arms have merged, and the torrential monsoon rains extend throughout south Asia. Animals mate and seeds germinate. Rivers, lakes, reservoirs, and wells fill with water. Humans plant and water their crops.

Monsoon rains continue through the summer months and begin to let up by the end of September. During many years, the rains that were so welcome in spring have become " too much of a good thing" by late summer, when flooding threatens crops, buildings, and lives throughout southern Asia. Soil and rock layers that hold water are saturated (completely full of water), and rainwater runs directly off the land surface. Small streams in the Himalayan foothills flow over their banks and flood crops and towns. Small floods run downhill to join others, and then flow together as a very large pulse of water into the mighty Brahmaputra and Ganges Rivers.

The Ganges-Brahmaputra system collects water from most of South Asia; the Indian province of West Bengal and the country of Bangladesh cover its massive delta (the fan-shaped area of land at the river's mouth). The residents of the Ganges Delta have developed some strategies for surviving the annual deluge, but there are years when particularly strong monsoon rains and heavy snows in the Himalayas create huge, uncontrollable floods that devastate the area. During floods in September 1998, almost 70% of Bangladesh, an area about the size of the state of Tennessee, was underwater. The 1998 floods in Bangladesh killed hundreds of people and caused millions to lose their homes. Poor sanitation and ruined crops led to widespread disease and starvation.

The dry season

In the fall, cold air flows down from the high peaks of the Himalayas as the continent begins to cool. A dry northwest wind blows across India and the rain moves offshore into the ocean. Floodwaters recede and leave behind new layers of silt (fine soil particles) and nutrients to fertilize the flooded agricultural lands. By the following July, the land is parched and dry, and south Asians look forward to another drenching rainy season.

Asian monsoon is a blessing and a threat

Plants and animals of South Asia depend on the summer rains and have evolved (changed over time) to survive the floods and droughts of the monsoon. Plentiful rain gives rise to lush forests and grasslands that provide food and shelter for some of Earth's most exotic animal species, including Bengal tigers and Indian elephants. South Asian plants and animals have adapted strategies to reproduce and thrive during the rainy season and then lie dormant (inactive) or survive on stored water during the dry months.

Approximately one quarter of the world's population depends on the monsoon rains and is threatened by related floods and droughts. The monsoon counties are very heavily populated. The land area of India is about the same size as the United States but its population is more than three times as large. Bangladesh, a relatively poor country, is one of the most densely settled places on Earth. (Imagine the entire population of the United States living in Oregon.)

Scientists have discovered links between the Asian monsoon and global climate. They worry that natural or human-induced global warming or cooling could affect the monsoon pattern and lead to increased drought or flooding. More than one billion people face starvation, illness, and the loss of their homes during exceptionally rainy or dry monsoon years. Natural ecosystems (interaction of living organisms and their environment in a community) of plants and animals that are suffer as well. The governments of monsoon countries, the United Nations, scientists, and non-profit organizations are working to better understand the monsoon and to develop solutions to economic and environmental problems of South Asia.

Laurie Duncan, Ph.D.

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Storms

Storms are disturbances in the atmosphere (air surrounding Earth) that bring severe weather: heavy rain and snow, high winds, lightning and thunder, tornadoes, and hail. There are storms that are mild, such as rainstorms, which are beneficial, bringing needed rainfall for plants, animals, and waterways. Yet storms also have the potential to cause great harm. Hurricanes batter coastlines and islands with high winds, drenching rain, and waves. Thunderstorms and blizzards can cause floods and dangerous traveling conditions. During thunderstorms, lightning can ignite brush fires, and hail can destroy crops. Tornadoes can cut swaths of destruction across anything in its path.

Storms occur in unstable or changing areas of the atmosphere where warm, light air rises rapidly from the land surface.

WORDS TO KNOW

Cyclone: Rotating atmospheric system of winds that flow into a low-pressure center. Cyclones rotate counterclockwise in the northern hemisphere and clockwise in the southern hemisphere.

Eye: Small circular area of relative calm at the center of a cyclone.

Front: The boundary between two air masses of different temperature and humidity.

Hurricane: A tropical cyclone in the Atlantic or eastern Pacific Oceans that has maximum wind speeds greater than 74 miles per hour.

Nor'easter: A gale or storm blowing from the northeast, particularly common in New England and eastern Canada.

Supercell thunderstorm: A large thunderstorm with a deep, rotating updraft that often produces hail and can spawn a tornado.

Tornado: A violently rotating column of air that is in contact with the ground.

Twister: Common name for a tornado.

Typhoon: Tropical cyclone in the western Pacific or Indian oceans.

Wall cloud: An area of clouds that extends beneath a severe thunderstorm an sometimes produces a tornado.

Waterspout: A column of rotating air, similar to a tornado, over a body of water.

A digital composite picture and animation from the movie *The Perfect Storm* shows a boat attempting to climb a mounting open sea wave driven by hurricane force winds. *The Kobal Collection. Reproduced by permission.*

The general conditions that spawn storms are well known; hot summer days in the American Midwest almost always produce thunderstorms. Cold air low pressure areas cause blizzards in the winter, which sweep eastward and warm seas feeding tropical low pressure systems cause hurricanes that spin from the tropical Atlantic Ocean from June through November. Predicting the exact location, severity, and timing of storms, however, is very difficult. Although weather forecasting and storm warning systems have become more accurate in recent years, severe weather still takes humans by surprise. Storms cause billions of dollars of damage and kill thousands of people each year around the world.

Thunderstorms

Thunderstorms form where plumes or masses of warm, moist air rise into cool air above. In temperate climates like central North America, thunderstorms are most common dur-

Waterspouts

Waterspouts are tornadoes over water. They look like transparent, water-filled ropes between the clouds and the sea or lake surface, and many people consider them beautiful (from a safe distance). Some waterspouts are tornadoes that moved over water, yet most form away from land. While they appear to suck water from the ocean, water spouts are actually spinning clouds of water droplets that changed from water vapor to liquid within the vortex (swirling center). Waterspouts are generally less dangerous and form more easily than tornadoes on land because they draw heat and moisture from their base as well as from their cloud. Waterspouts often form beneath puffy, white fair- weather clouds, and occasionally under clear skies. Scientists have observed waterspouts with wind speeds greater than 190 miles per hour (306 kilometers per hour). As such, they pose a significant hazard to boats and airplanes. Waterspouts may account for some mysterious disappearances within the so-called "Bermuda Triangle," where boats and planes have vanished.

ing the spring and summer, but they can also form in the winter. Temperature differences between rising areas of warm air and cool air surrounding them create air currents (moving stream of air) called updrafts and downdrafts. Vertically (upwards and downwards) circulating thunderstorm clouds have central updrafts (areas of rising air) surrounded by a ring of downdrafts (areas of falling air). Tall, billowing, black clouds form, called cumulonimbus clouds or thunderheads. Heavy rain falls. Moving water and ice particles within the clouds create electrical charges, causing lightning bolts to zap between clouds and the ground. Thunder booms and crackles. Thunder is the sound created by the electrical discharge of lightning.

Three ingredients are a recipe for a thunderstorm: warm, moist air near the land surface; cool, dry air above; and something to lift the warm air. Mountain ranges, moving weather fronts (a line between two air masses with differing characteristics, bringing changing weather), converging winds, and uneven heating of land and sea surfaces can all provide an upward push. Sometimes, the rising air is fairly dry, and clouds form that produce lightning but no rain. A line of thunderstorms can form along the moving front of an air mass. In the summertime, thunderstorms roll across the American Great Plains each afternoon as the land surface heats unevenly. Afternoon lightning and cloudbursts are very common in the Rocky Mountains when warm, moist air rises up the face of the mountain. Most thunderstorms are short-lived, single cell (brief, small) and multi-cell storms (storms with multiple storm-producing clouds) that may produce lightning and heavy rain, but rarely cause severe damage. The most intense thunderstorms, called supercells, will produce battering hail, flash floods, high winds, and tornadoes.

Tornadoes

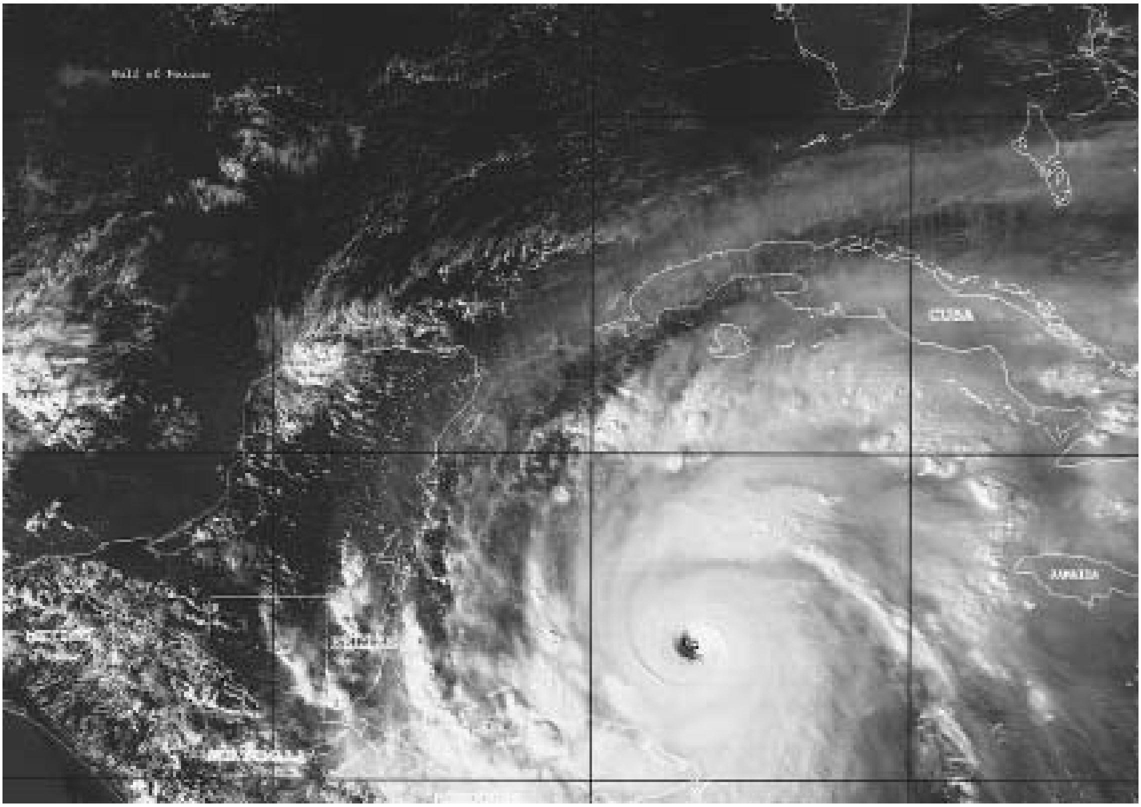
Tornadoes, or twisters, are narrow columns of violently spinning air that extend, finger-like, from the bases of cumulonimbus clouds during intense supercell thunderstorms. Tornadoes form when instability within the storm causes spiraling air circulation. The base of the storm cloud lowers, and becomes a spinning cloud called a wall cloud. Wall clouds can sometimes develops protruding lumps called mammatus clouds. Tornadoes are whirlpools of upward-moving air that descend from the parent wall cloud to the ground. The portion of a tornado that actually touches the ground is usually quite small. Numerous accounts describe twisters that completely destroy a structure while leaving an immediate neighbor's property untouched. Small whirlwinds like dust devils (small, circular, brief winds on land) and some waterspouts (a column of rotating air, similar to a tornado, over a body of water) can also develop away from a parent thunderstorm.

Sailors watch a waterspout from the deck of a US warship at sea off Shanghai, China. © *Hulton-Deutsch Collection/Corbis. Reproduced by permission.*

Meteorologists (weather scientists) classify tornadoes as weak, strong, or violent. Weak and strong tornadoes spin less than about 200 miles per hour (322 kilometers per hour). They can knock over trees, pick up objects and fling them like missiles, demolish mobile homes, and tear roofs from framed houses. Violent tornadoes can completely destroy a well built home or lift a large object like a car. Thankfully, these are quite rare; only two twisters out of every hundred have winds that exceed 200 miles per hour (322 kilometers per hour). A tornado like the one that tore Dorothy's house from the ground and lifted it into the air during a dream in L. Frank Baum's story *The Wizard of Oz* is thus unlikely, but not impossible. Dorothy's home, Kansas, is at the center of "Tornado Alley," where severe thunderstorms spawn tornadoes that rake across the plains between the Rockies and Appalachian mountains during the spring and summer.

Tropical cyclones

Tropical cyclones are huge, spiral-shaped storm systems that form near the equator in the Atlantic, Pacific, and Indian Oceans. Warm, tropical waters fuel their growth from groups of individual thunderstorms, into massive, organized systems of circulating winds and clouds. Tropical cyclones in the Atlantic and eastern Pacific Ocean are called hurricanes. Western Pacific cyclones are called typhoons, and those in southern Pacific and Indian Oceans are simply called cyclones. Earth's rotation caus-



Hurricane Mitch spirals through the Caribbean. *National Oceanic and Atmospheric Administration. Reproduced by permission.*

es winds to blow hurricanes and typhoons in the Northern Hemisphere to spin counter-clockwise (east to west). In the southern hemisphere, winds move west to east, causing hurricanes and cyclones to spin clockwise.

Atlantic hurricanes originate from a near-permanent band of thunderstorms near the equator. Warm water and converging trade winds (surface winds blowing westward in the tropics and sub-tropics) create updrafts of moist air that feed huge thunderstorms and dense rain clouds. The first stage of a developing hurricane, called a tropical depression, forms when a group of thunderstorms organizes around a particularly large storm and begins to rotate.

Some, but not all, tropical depressions grow into tropical storms and then into hurricanes. Tropical storms have more organized spiral patterns and stronger winds than tropical depressions. Although tropical storms are not as powerful as full-fledged hurricanes, they bring very heavy rainfall and often cause severe flooding. Tropical storms officially become hurri-

Hurricane Andrew

Hurricane Andrew battered the Bahamas, Florida, and the Gulf Coast of the United States with fierce winds, high waves, and heavy rain in August 1992. With wind speeds that exceeded 175 miles per hour (282 kilometers per hour), Andrew was one of only three category 5 hurricanes in the twentieth century. (Galveston, 1900, and Camille, 1979, also were rated category 5.) Andrew swept through the islands of the Bahamas, plowed across south Florida, and then turned north in the Gulf of Mexico. The storm regained its intensity before making landfall in south central Louisiana and weakening. More than 200,000 people were evacuated from their homes in Florida, Louisiana, and Texas.

Hurricane Andrew was by far the most expensive natural disaster in U.S. history. Damage to buildings, offshore oil rigs, bridges, roads, and other structures in Florida, the Gulf of Mexico, and Louisiana exceeded $25 billion. According to the *Miami Herald,* Andrew destroyed almost all the mobile homes in two Florida counties. Boats alone sustained $500 million of damage. Had Andrew been slightly wider, or had it taken a slightly different path, the damage would have been much worse. In Florida, Andrew moved just south of the highly-populated beachfront cities of Miami and Ft. Lauderdale. In Louisiana, New Orleans escaped relatively untouched (a storm surge from a large hurricane could easily overflow the levees that protect New Orleans from catastrophic flooding.)

Hurricane Andrew caused remarkably little loss of human life for a storm of its intensity. It affected an area populated by hundreds of thousands of people, but the storm directly or indirectly caused fewer than 60 deaths. U.S. and Bahamian officials were able to prepare for Andrew using weather forecasting technology, storm warning broadcast systems, and pre-planned evacuation procedures. The residents of Galveston Island had no such advance warning when the category 5 hurricane struck their seaside community on September 8, 1900. More than 6,000 people died when the 16-foot (5 meters) tall storm surge washed across the 9-foot (3 meter)-high (above sea level) island. Thanks to advances in meteorology and communication, human lives were spared, and property instead suffered the brunt of Andrew's wrath.

canes when its winds exceed 74 miles per hour (119 kilometers per hour). A small area of calm, called the eye, forms at the center of the storm. The eye wall, a ring of intense winds and heavy rain, surrounds the eye. Bands of rain and clouds spiral out to the edges of the storm. Meteorologists rate hurricane intensities from category 1 to category 5. Hurricanes stronger than category 3 (wind speeds greater than 111 miles per hour or 179 kilometers per hour) generally cause extensive damage when they make landfall.

Atlantic tropical storms and hurricanes ride the warm Gulf Stream current (a warm northbound surface current that carries Atlantic Ocean water into the Norwegian Sea) northwest from the tropics toward the Caribbean Sea, Gulf of Mexico, and Atlantic coast of the United State. Tropical cyclones depend on warm ocean water to feed warm, moist air into their central updrafts, so they fade when they move over cool water or land. Tropical cyclones take several weeks to develop and move across the ocean before subsiding, and there may be several storms in a particular ocean at one time. To avoid confusion, meteorologists assign names to tropical storms and hurricanes using alphabetical lists of alternating male and female names. The first storm of the year has a name starting with A, the second with B, and so on. (There are no names beginning with Q, U, or Z.) The 2004 list for the Atlantic Ocean included such early-in-the-alphabet names as Charley, Frances, and Ivan. There are six lists, so these names will be used again in 2010. The names of very large and destructive hurricanes like Camille (1969), Hugo (1989), and Andrew (1992) are retired from the list.

Mid-latitude cyclones

Mid-latitude (areas midway between the equator and the poles) cyclones cause most of North America's stormy weather. Like tropical cyclones, mid-latitude cyclones are low-pressure systems that rotate counterclockwise in the Northern Hemisphere. Westerly (east-blowing) winds drive air masses across North America from west to east. Easterlies blow cold air to the west in northern Canada. Mid-latitude cyclones develop when a cool, dry air mass follows a warm, moist one. (The leading edge of the cool air mass is called a cold front.) Some of the warm air flows north (left) toward Canada, and some of the cold Canadian air blows south (left) creating a counter-clockwise spiral with rising air, and low pressure, at its center.

Storms form along the cold front and in the low pressure zone where warmer, moist air is forced up into the overlying cold air. Warm air moving north from the Gulf of Mexico provides moisture to fuel winter blizzards and summer thunderstorms in Great Plains. Cyclones also draw moisture from the Great Lakes and drop heavy rain and snow downwind to the east. When a large cyclone reaches the northeast coast of North America, the spiraling winds extend over the North Atlantic and pick up more moisture and then blow back toward the continent. Nor'easters are cold, wet storms that blow into Maine, Nova Scotia, New Brunswick, and Newfoundland from the northeast.

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Weather

Weather is the state of the atmosphere (mass of air surrounding Earth) at a particular place and point in time. Rain showers, gusty winds, thunderstorms, cloudy skies, droughts (prolonged period of dry weather), snowstorms, and sunshine are all examples of weather conditions. Weather scientists, called meteorologists, use measurable factors like atmospheric pressure (pressure caused by weight of the air), temperature, moisture, clouds, and wind speed to describe the weather. Meteorologists make predictions of future weather based on observations of present regional weather patterns and past trends. Weather prediction, or forecasting, is an important part of meteorology (weather science). Advance warning of such weather phenomena as extreme hot and cold temperatures, heavy rainfall, drought, and severe storms can protect people's property and save lives.

The weather patterns that a region experiences over tens, hundreds, or thousands of years are called climate. For example, the northeastern United States experiences a wide range of weather during an average year. Below-freezing temperatures and heavy snowfall are typical weather conditions in winter,

WORDS TO KNOW

Air mass: Large body of air with only small variations of temperature, pressure, and moisture.

Air pressure: Force exerted by the weight of a column of air above a particular location.

Anticyclone: An atmospheric system associated with dry, clear weather with winds that spiral out away from a center of high atmospheric pressure.

Atmospheric (barometric) pressure: Pressure caused by the weight of the atmosphere over a surface or object.

Barometer: An instrument used to measure atmospheric pressure.

Cyclone: An atmospheric system associated with stormy weather with winds that spiral in toward a center of low atmospheric pressure.

Front: A boundary between air masses.

Humidity: Water vapor (moisture) in the air.

Jet stream: High-speed winds that race around the planet at about five miles above the Earth.

Meteorology: The science of atmospheric conditions and phenomena.

Trade winds: Persistent tropical winds that blow generally toward to west in both hemispheres in most of the tropics and subtropics.

while warm temperatures and afternoon thunderstorms are common in the summer. Communities of plants and animals (ecosystems) adapt over thousands of years to survive the weather extremes of their particular climate. In New England, plants lie inactive, mammals grow shaggy coats, and birds fly south during the cold dark winter. In the spring, trees pull sap from their roots and grow leaves, animals bear young, and seeds germinate in time to take advantage of mild temperatures and long, sunny days in the summer. Climate change happens over hundreds and thousands of years, but weather varies from day to day, hour to hour, and sometimes from minute to minute.

Weather conditions: pressure, temperature, and moisture

The atmosphere presses down on Earth's surface. (There is no atmosphere in outer space. Without their pressurized space suits, astronauts' bodies would explode.) The weight of the column of air molecules above a surface is called atmospheric pressure. The average weight of the atmosphere on one square inch of ground at sea level is 14.7 pounds. People do not feel this pressure because their senses are adjusted to it and the human body is designed to withstand it.

Meteorologists use an instrument called a barometer to measure pressure, and atmospheric pressure is also called barometric pressure. Evangelista Torricelli (1608–1647), an Italian physicist, invented the barometer in 1643. His instrument, "Torricelli's tube," was a glass tube full of dense, liquid mercury with its end in an open dish of mercury. His barometer works the same way that mercury barometers work in modern day. Air pressing down on the mercury in the dish pushes some of the mercury upwards into the glass tube. As air pressure increases, the mercury in forced into the tube and the column of mercury rises. When air pressure decreases, the mercury flows back into the dish and the column of falls. Barometric pressure is often measured in inches of mercury. When a weather forecaster says the mercury is falling, it means that air pressure is falling, and bad weather may be approaching.

Atmospheric pressure differs from one place on Earth to another due to temperature, moisture, and topography (physical surface features). Pressure decreases with elevation. There are many fewer air molecules above a square foot (kilometer) on the summit of Mt. Everest than above a square foot of Waikiki Beach. Air currents, better known as winds, blow from areas of high pressure to areas of low pressure. Rapidly chang-

Weather Forecasting

A drawing of an early aneroid barometer used to predict changes in the weather. *National Oceanic and Atmospheric Administration. Reproduced by permission.*

Meteorologists use weather indicators like barometric pressure and cloud types, maps of large-scale weather patterns, and data from previous years to predict upcoming temperature, moisture, and severe weather conditions. News outlets like television, radio, and newspapers broadcast forecasts to the public. In emergencies, they broadcast severe weather warnings and information on how to take shelter during floods and storms. In the United States, the National Weather Service provides specific forecasts for pilots and ship captains who need more detailed information. They also provide storm warnings and recommendations for emergency procedures during severe weather. The U.S. Farm report provides weather information specifically for farmers who use forecasts to plan their planting, harvesting, and irrigation schedules.

Weather prediction is a tricky business. In some places, atmospheric conditions lead to continuously changing weather. Mark Twain said of New England, "If you don't like the weather, wait ten minutes." In other places, weather patterns are generally so predictable that changes take people by surprise. Winter-weary residents of North Dakota say, "If summer happens on a Saturday, we'll have a picnic." While everyone from pilots to party planners knows that weather forecasts are never perfect, people still depend on forecasts to help plan for the future. Weather forecasts provide vital advance warning of severe weather such as hurricanes, tornadoes, and floods that can pose a serious threat to lives and property.

Modern meteorologists use a variety of techniques to measure atmospheric conditions and generate forecasts. Maps of barometric pressures, temperatures, and rainfall amounts help meteorologists spot weather trends like cyclones, anticyclones, fronts, air masses, and storm systems. Weather radars, satellite maps, and computer-generated models of future weather help weather scientists make precise measurements, continuously updated forecasts, and more complex predictions. Other methods have been used by observant people for hundreds of years For example, some flowers close their petals before it rains, high clouds and falling atmospheric pressure signal an approaching cold front, and dogs sense thunder before humans.

Other weather lore is probably more myth than reality. Many people still believe the theory that a groundhog's shadow predicts an additional six weeks of winter, or that cows lie down before it rains.

ing patterns of winds, precipitation (any form of water falling), clouds, and storms develop around moving high and low pressure centers in Earth's atmosphere.

Temperature affects air pressure and moisture in the atmosphere. Warmer air expands and rises, so pressure falls beneath rising columns of warm air. Warm air also holds more moisture, in the form of water vapor, than cool air. Rising warm air in low pressure zones often carry water vapor high into the atmosphere. When the warm air begins to cool, the moisture condenses into droplets or freezes into ice crystals and clouds form. Precipitation and storms are common in low-pressure centers. As air cools it contracts, causing air pressure to rise under the sinking air. Because cool air holds less moisture, and because sinking air masses are usually already dry, high pressure areas usually are low in humidity (air moisture).

High and low pressure systems

Major east and west-blowing winds blow high and low-pressure weather systems around Earth. High-pressure systems, also called anticyclones, consist of winds spiraling out from a high-pressure center under sinking, dry air. Low-pressure systems, or cyclones, have low-pressure centers and winds that spiral toward their centers. High-pressure systems are called anticyclones. A cyclone has a column of warm air rising from its center. In anticyclones, the air sinks toward the center and warms as it descends. In the northern hemisphere (half of the Earth), anticyclones spin clockwise and cyclones spin counterclockwise, and the reverse is true in the southern hemisphere. Because air travels from high to low pressure areas, high-pressure anticyclones often follow low-pressure cyclones.

In North America, the jet stream (high-speed winds that race around the planet at about five miles above the Earth) blows cyclones and anticyclones from west to east. In general, cyclones bring intense weather in the form of rain, snow, clouds, and storms. Dry, clear, calm weather usually accompanies the passage of anticyclones. (The parched residents in deserts of the American Southwest might look forward to the clouds and rain storms a cyclone brings. A southward dip in the Jet Stream causes a near-permanent zone of high pressure over Arizona, New Mexico, and Southern California, and moisture-bearing weather systems tend to bypass the region.) Trade winds (persistent tropical winds that blow generally toward the west) blow low-pressure systems that develop in the tropical Atlantic Ocean west toward the Caribbean Sea and east coast of the United States. These tropical cyclones feed on warm ocean waters and can develop into massive storm systems called tropical storms and hurricanes.

Air masses and fronts

An air mass is a large body of air that has similar temperatures and moisture content throughout. Several air masses contribute to weather patterns in North America: cold, dry air over northern Canada; hot, dry air in the American Southwest; cool, moist air moving east over the Pacific Northwest; and warm, moist air traveling north from the Gulf of Mexico.

The boundaries between air masses are called fronts. A cold front occurs where a cold air mass is moving in to replace warm air. Clouds, precipitation, and storms are common at cold fronts. The incoming cold, dense mass lifts the warm, moist air and creates unstable conditions where moisture rapidly condenses and winds organize clouds into storms. Once a cold front has passed, temperatures and humidity drop and a high-pressure system moves in. A warm front precedes an incoming warm air mass. Warm fronts bring moisture and higher temperatures. Stationary fronts separate unmoving air masses.

A typical cyclone in the American Mid-West is a rotating pinwheel of three air masses and three fronts moving east toward the Atlantic Ocean. Cold, dry air flows south from Canada behind cool, moist air flowing from the Pacific Northwest. Warm air from the Gulf of Mexico moves north and contributes moisture to the system. Thunderstorms and blizzards develop along cold fronts.

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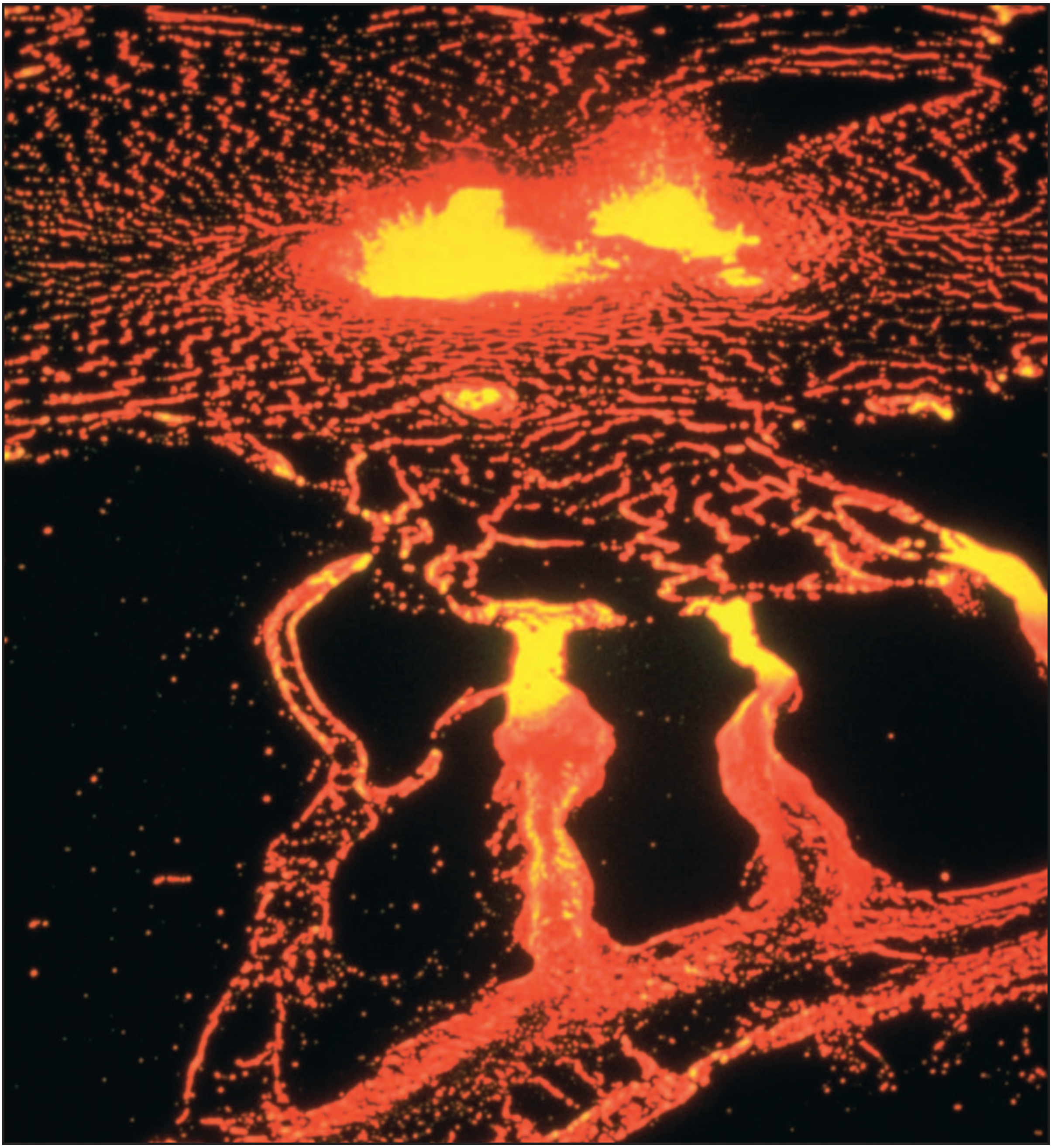
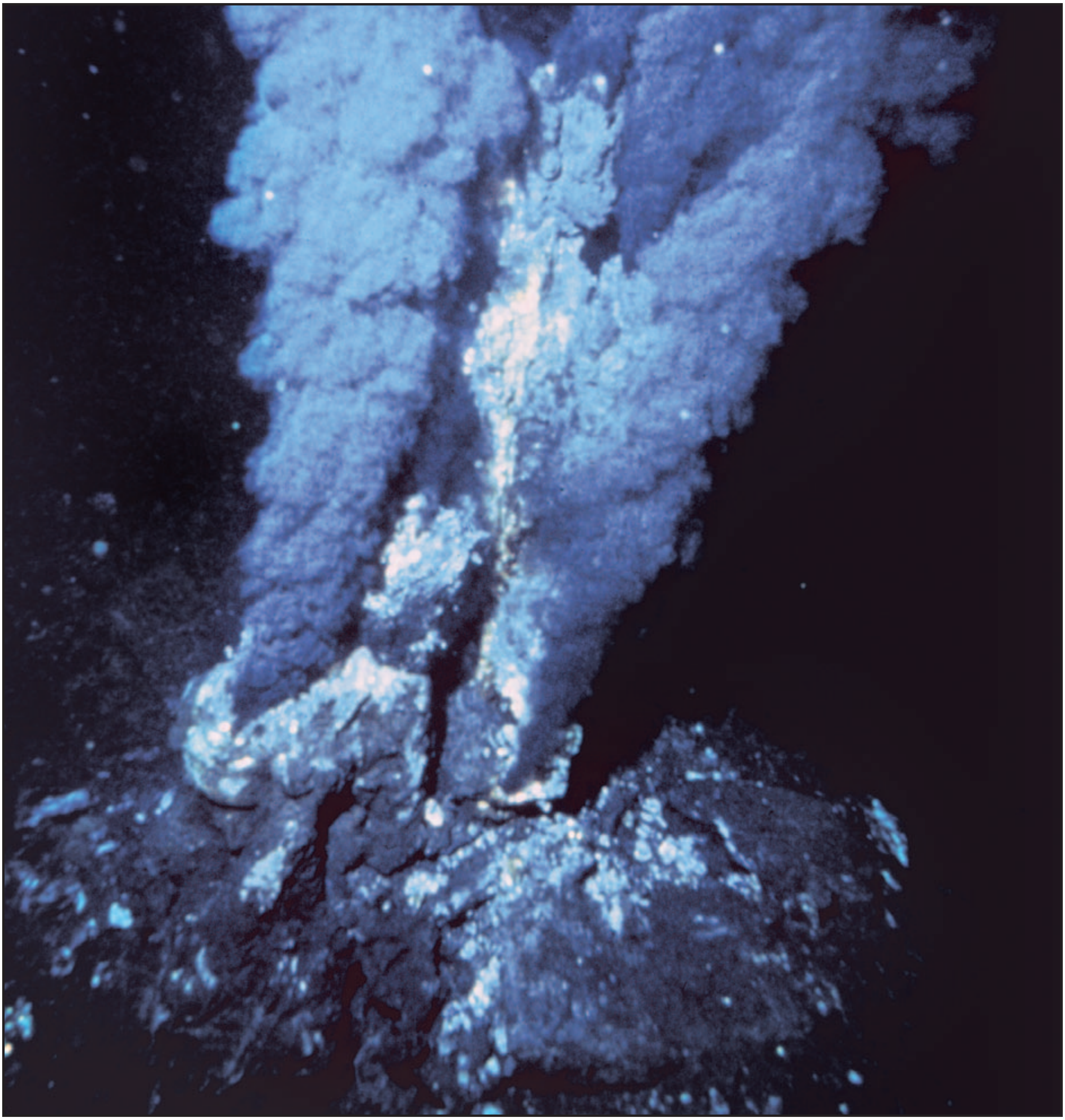


Above: Lava spewing from Kilauea volcano in Hawaii runs seaward. See "Islands" entry. *JLM Visuals. Reproduced by permission.*



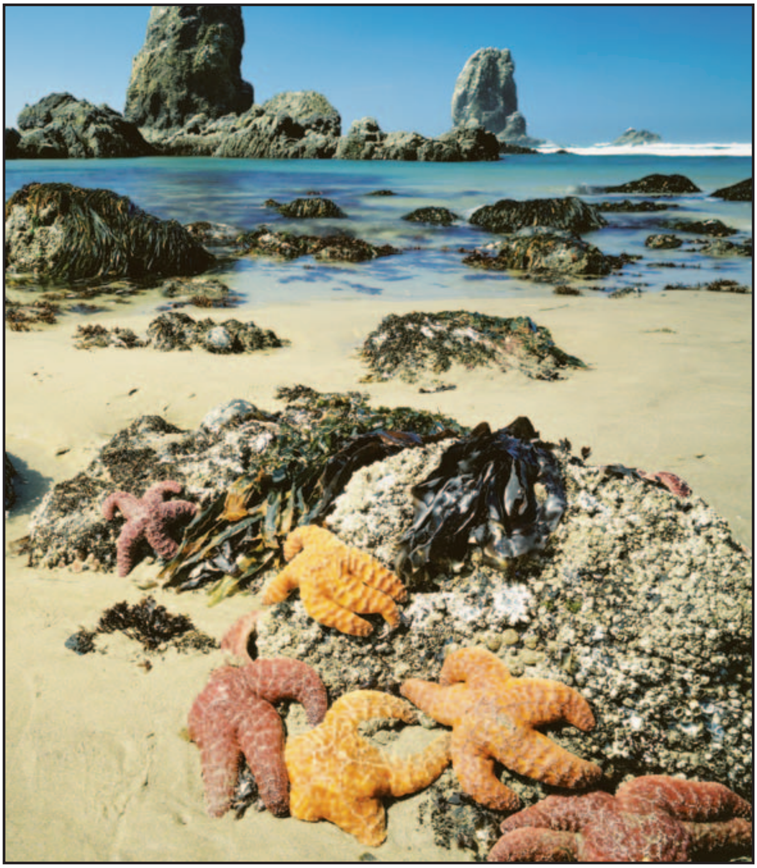
Above: A black-smoker hydrothermal vent near the Endeavor Ridge off the coast of California. See "Biology of the Oceans" entry. *P. Rona. OAR/ National Undersea Research Program (NURP)/National Oceanic and Atmospheric Administration. Reproduced by permission.*

Above: Krill swimming in open ocean waters off Antarctica. See "Biology of the Oceans" entry. *© Peter Johnson/Corbis. Reproduced by permission.*

Right: The *Sojourner* rover performs experiments on Mars. See "Biochemistry (Water and Life)" entry. *Courtesy of NASA/JPL/Caltech. Reproduced by permission.*

Left: Sockeye salmon swimming upstream in the Brooks River, Alaska. See "Freshwater Life" entry. © *Ralph A. Clevenger/ Corbis. Reproduced by permission.*

Below: Clouds are formed from water in the atmosphere. See "Clouds" entry. © *Joseph Sohm, ChromoSohm Inc./Corbis. Reproduced by permission.*

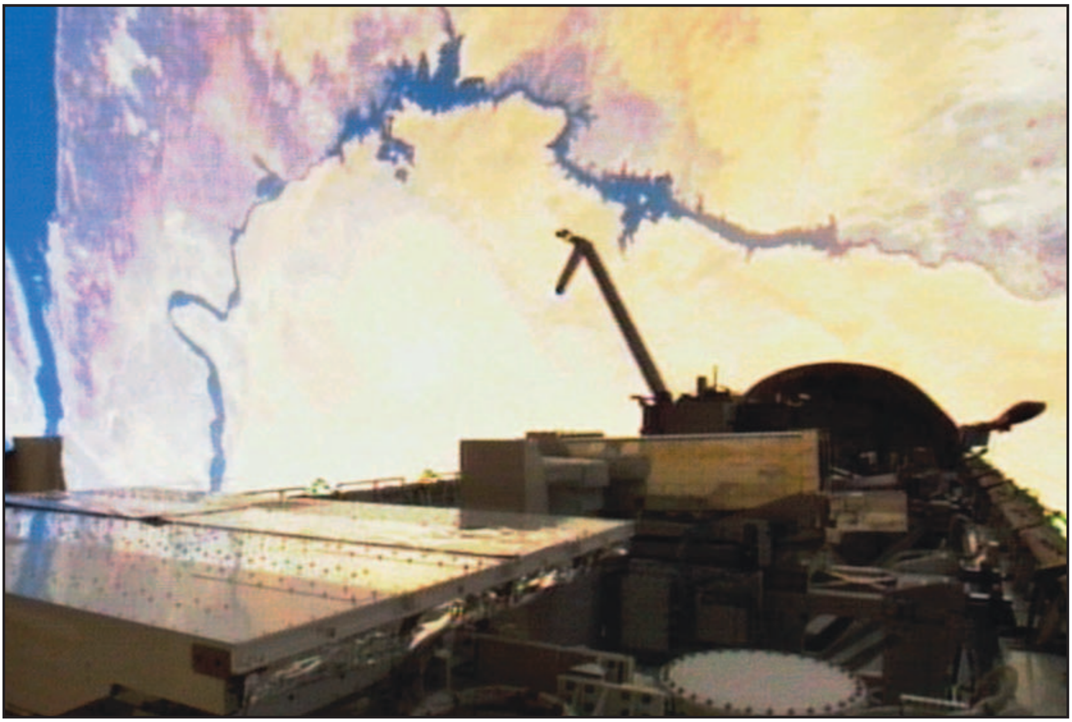


Right: Starfish cling to rocks on a sandy beach. See "Coastlines" entry. © *Craig Tuttle/ Corbis. Reproduced by permission.*

Below: Flags mark the ceremonial South Pole, while the true South Pole is visible in the distance. See "Polar Ice Caps" entry. © *Galen Rowell/Corbis. Reproduced by permission.*

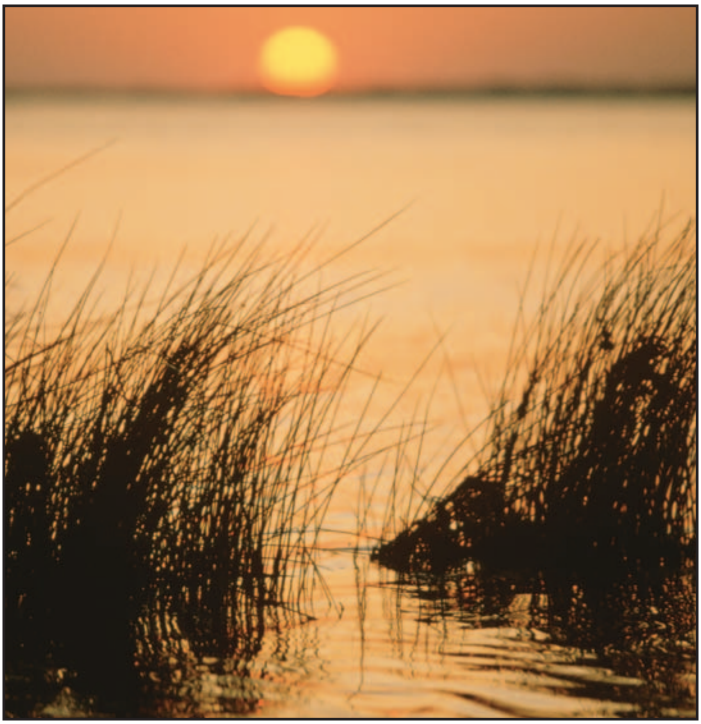
Left: A tower of the Golden Gate Bridge rises above the fog covering San Francisco Bay. See "Clouds" entry. © *Morton Beebe/Corbis. Reproduced by permission.*

Below: The space shuttle *Endeavor* passes over the Nile River. See "Rivers" entry. *AP/Wide World Photos. Reproduced by permission.*



Above: A school of blackbar sunfish passes a sunken plane off the shore of Jamaica. See "Fish (Saltwater)" entry. © *Stephen Frink/Corbis. Reproduced by permission.*

Right: A moon jellyfish, a marine invertebrate, approaches a diver off the Florida Keys. See "Marine Invertebrates" entry. © *Stephen Frink/Corbis. Reproduced by permission.*



Above: The rapid currents and small waterfalls of a stream through the Willamette National Forest provide a home to many species of aquatic life and provide a vital water source to land-based life. See "Freshwater Life" entry. *© Steve Terrill/Corbis. Reproduced by permission.*

Left: Grasses grow along the banks of an estuary of the Chesapeake Bay. See "Estuaries" entry. *© Raymond Gehman/Corbis. Reproduced by permission.*