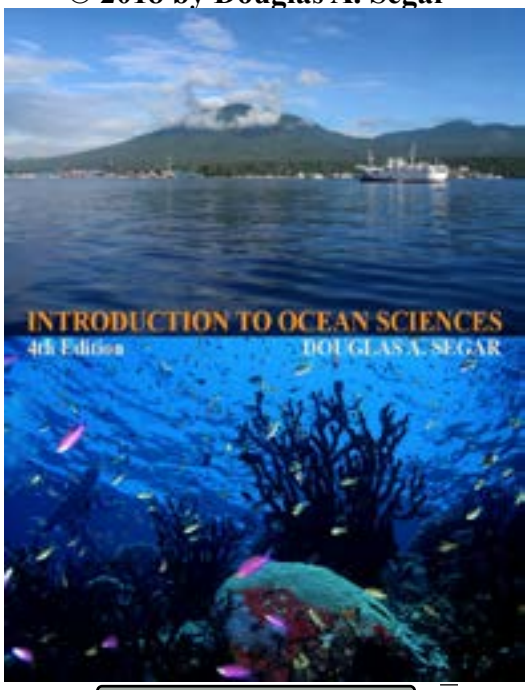
Introduction to Ocean Sciences

Fourth Edition, Second digital edition ver 4.0

DOUGLAS A. SEGAR

Contributing author Elaine Stamman Segar



Library of Congress Cataloging-in-Publication Data

Segar, Douglas A.
Introduction to ocean sciences / Douglas A. Segar with contributions from Elaine Stamman Segar
p. cm.
ISBN: 978-0-9857859-1-8
1.Oceanography. I. Title

Glossary

absorption spectrum (pl. **spectra)**. Wavelengths of electromagnetic energy that substances can absorb and convert to heat. Absorption spectra are plotted as the relative efficiency of absorption versus wavelength. Compare *emission spectrum*.

abyssal fan. Fan-shaped sediment accumulation spreading out and decreasing in thickness from a point of large sediment input. Abyssal fans are located usually off the mouth of a river or at the foot of a submarine canyon.

abyssal hill. Sediment-covered volcanic peak that rises less than 1 km above the deep-ocean floor.

abyssal plain. Flat seafloor extending seaward from the base of the continental slope and continental rise or from the seaward edge of an oceanic trench. **abyssal zone**. Benthic environment between 4000 and 6000 m depth.

acid rain. Rain with acidity higher than normal because of dissolved gaseous emissions of industry and automobiles, notably sulfur compounds.

acidification. An increase of hydrogen ion concentration to make a solution more acidic or less alkaline. In ocean acidification refers to the addition of anthropogenic carbon dioxide to the oceans that reduces the pH and renders cacium carbonate more soluble.

acoustic. Pertaining to sound.

adiabatic expansion. Expansion of a gas without the addition of external heat. Adiabatic expansion causes the temperature of the gas to decrease. Adiabatic compression causes the temperature of the gas to increase.

adsorption (adj. **adsorbed)**. Attraction and adhesion of ions to a solid surface.

aerobic. In the presence of oxygen.

algae (sing. **alga)**. Simple single-celled or many-celled photosynthetic organisms that have no root, stem, or leaf systems. See Appendix 3.

algal ridge. Irregular ridge located on the wave-exposed seaward edge of many coral reefs. The ridge is composed largely of encrusting algae.

alkalinity (adj. **alkaline)**. The opposite of acidity. Measure of the degree to which the concentration of hydroxyl ions (OH^-) is greater than the concentration of hydrogen ions (H^+) in a solution. Seawater is slightly alkaline.

amino acids. Members of a group of compounds that combine in varied proportions to form proteins.

amoebas. Microscopic single-celled animals that move by making continuous protrusions of the body and that feed by engulfing bits of food. See Appendix 3.

amphidromic system. Tide wave that rotates around an ocean basin during one tidal period. An amphidromic system rotates around an amphidromic point (a node) at which the tidal range is zero.

amphipods. Members of an order of the subphylum Crustacea, phylum Arthropoda, that includes laterally compressed species such as the "sand hoppers." See Appendix 3.

amplitude. Vertical distance from the mean level of a wave (the still sea surface for an ocean wave) to the crest or to the trough. A wave's amplitude equals one-half of the wave height.

anadromous. Pertaining to species of fishes that are spawned in freshwater, migrate to the ocean to live until they reach maturity, then return to freshwater to spawn. Compare *catadromous*.

anemones. Multicelled animals of the class Anthozoa, phylum Cnidaria. There are both single and colonial polypoid forms. See Appendix 3.

angle of incidence. Angle between a wave front (usually an electromagnetic wave) or a wave ray and the plane of an interface that it meets. Angle of approach. The angle of incidence is important in refraction.

anion. Negatively charged ion. Compare *cation*.

annelids. Members of the phylum Annelida. Elongated segmented worms. See Appendix 3.

anoxia (adj. **anoxic)**. Total absence of dissolved or free molecular oxygen. Compare *hypoxia*.

anthropogenic. Produced by people and their activities.

antinode. The part of a standing wave where the vertical motion is at a maximum. Compare *node*.

aphotic zone. The part of the ocean in which light is insufficient for photosynthesis. The aphotic zone comprises all the oceans below about 1000 m in areas where ocean water is clear and extends to shallower depths in more turbid waters. Compare *photic zone*.

aragonite. A mineral form of calcium carbonate. Aragonite is less common than calcite, but it comprises shells of many pteropod species.

archaea (sing. **archaean;** adj. **archaeal)**. Microorganisms of the domain Archaea (previously called Archaeobacteria) that belong to an ancient group of organisms that are separate from bacteria and from which eukaryotes (multicelled organisms) may have evolved. Many archaeal species are chemosynthetic and live in extreme environments. See Appendix 3.

aspect ratio. Index of the propulsive efficiency of a fish species that is obtained by dividing the square of the height of the caudal fin by the area of the caudal fin.

assimilative capacity. Maximum rate at which a particular segment of the environment or ocean can accommodate the input of a substance. The term usually applies to anthropogenic waste materials.

asteroid. Rocky object orbiting the sun. An asteroid is smaller than a planet. Most asteroids are found in a belt between the orbits of Mars and Jupiter, but some have orbits that take them close to the sun and across the orbits of the planets.

asthenosphere. Plastic or partially molten layer of the Earth's upper mantle upon which the continents "float." The asthenosphere varies in thickness, with its upper boundary at depths of 10 km or more and its lower boundary at depths as great as 800 km.

atoll. Ring-shaped coral reef that grows upward from a submerged volcanic peak and encloses a lagoon. Atolls may support low-lying islands composed of coral debris. Compare *barrier reef* and *fringing reef*.

autotrophs (adj. **autotrophic)**. Algae, bacteria, archaea, or plants that can synthesize organic compounds from inorganic nutrients by photosynthesis or chemosynthesis. Compare *heterotrophs*.

back-arc basin. Generally shallow sea created on the non-sub-

ducting plate at an oceanic convergent plate boundary where the subduction is fast enough to stretch the edge of the non-subducting plate. The back-arc basin lies behind the volcanic island arc. Also called "back-island basin."

backscatter (adj. **backscattered)**. The portion of the light or sound randomly reflected off particles suspended in a fluid that is scattered back in the general direction of the light or sound source. Compare *scatter*.

backshore. Inner portion of the shore that is landward of the mean spring-tide high-water line. Waves act on the backshore only during exceptionally high tides and severe storms. Compare *foreshore*.

backwash. Water flowing down a beach after the swash of one wave has stopped and before the swash of the next wave arrives.

bacteria (sing. **bacterium;** adj. **bacterial)**. Microscopic single-celled organisms that comprise one of the three recognized biological domains. Other than cyanobacteria, most bacteria species are autotrophs and decomposers, and most are parasitic. They reproduce by cell division. See Appendix 3.

baleen. Horny material consisting of numerous plates with fringed edges that grows down from the upper jaw of plankton-feeding whales. Baleen is used to filter (strain) the plankton food from the water.

bar-built estuary. Shallow estuary (lagoon) separated from the open ocean by a bar such as a barrier island. Water in bar-built estuaries is usually well mixed vertically.

barnacles. Members of an order of the subphylum Crustacea, phylum Arthropoda, that attach to the substrate, secrete a protective covering of calcareous plates, and strain food particles from the water with a weblike structure. See Appendix 3.

barrier island. Long, narrow island built of wave-transported sand, separated from the mainland by a usually shallow lagoon.

barrier reef. Coral reef that parallels the shore but is separated from the landmass by open water. Compare *fringing reef* and *atoll*.

basalt (adj. **basaltic)**. Dark-colored volcanic rock, rich in iron, magnesium, and calcium, characteristic of the oceanic crust.

bathyal zone. Benthic environment from 200 to 2000 m depth.

bathymetry (adj. **bathymetric)**. Seafloor mapping; the study of landform features beneath the water surface. A bathymetric map gives the depth contours of the seafloor.

baymouth bar. Shallow bar, usually of sand, that extends partially or completely across the mouth of a bay.

beach. Sand- or sediment-covered zone between the seaward limit of permanent vegetation and the mean low-water line. Beaches sometimes include the seafloor from the mean low-water line to the surf zone.

benthic. Pertaining to the seafloor, or to organisms that live on or in the seafloor.

benthos. Organisms that live on or in the ocean bottom.

berm. Nearly horizontal portion of a beach backshore at the seaward edge of which the beach slopes abruptly seaward. Compare *scarp*.

bioaccumulation (v. **bioaccumulate)**. Process by which dissolved chemicals are taken up by organisms until the concentrations in the tissues are at equilibrium with those in the solution. See **CC18**.

bioassay. Test in which organisms are exposed to different concentrations of a substance to determine the concentration at which the substance is toxic to that species. See **CC18**.

bioavailable. Existing in a chemical form that is suitable for uptake by organisms.

biochemical. Pertaining to the synthesis, conversion, use, and decomposition of organic chemicals in the life processes of organisms.

biodegradable. Capable of being decomposed by organisms in the environment. The term generally refers to decomposition to harmless substances.

biodiversity. Poorly defined term that refers to a combination of genetic diversity, species diversity, ecosystem diversity, and physiological diversity within a community or ecosystem. See **CC17**.

biogenous. Pertaining to material of a biological origin. Usually applied to sediments in which the hard-part remains of organisms (e.g., diatom tests, radiolarian shells) constitute a high proportion of the grains. Compare *cosmogenous*, *hydrogenous*, and *lithogenous*.

biogeochemical cycle. Transfers of compounds among the living and nonliving components of an ecosystem.

bioluminescent. Light-producing. Referring to organisms that use chemical reactions to produce light.

biomagnification (v. **biomagnify)**. Process by which dissolved chemicals are taken up by organisms and continuously accumulated to higher concentrations throughout the life cycle. Tissue concentrations are not in equilibrium with concentrations in the surrounding environment. See **CC18**.

biomass. The total amount of living matter, expressed in units of weight in the entire water column per unit area of water surface, or weight per unit of water volume.

biota. All living organisms in a given ecosystem, including archaea, bacteria, protists, fungi, algae, plants, and animals.

bioturbation. Reworking (churning and mixing) of sediments by organisms that burrow in them.

bloom. Very dense aggregation of phytoplankton, resulting from a rapid rate of reproduction.

blubber. Outer fat layer of whales.

blue-green algae. See *cyanobacteria*.

brackish. Pertaining to water that is a mixture of freshwater and seawater and has a low salinity.

breakwater. Artificial structure constructed in the ocean to protect a shore from the action of ocean waves

brine. Water that has a higher salinity (generally much higher) than normal seawater.

brittle stars. Organisms of the class Ophiuroidea, phylum Echinodermata, that have long, slender arms covered in bristles attached to a small central disk. See Appendix 3.

bulkhead. Structure constructed to separate land and water areas at the shoreline and designed to reduce earth slides and slumps or to lessen wave erosion at the base of a cliff.

buoyancy (adj. **buoyant)**. Ability of an object to float (or rise through a fluid) that results from a density difference between the object and the fluid in which it is immersed.

bycatch. Fishes and other marine animals caught in fishers' nets that are not the target of the fishing. Bycatch is generally thrown overboard as waste.

calcareous. Composed of or containing calcium carbonate.

calcite. The most common mineral form of calcium carbonate. Compare *aragonite*.

caldera. Crater in a volcano, usually at the center, created by an explosion or collapse of the volcanic cone.

calorie. Obsolete unit of heat energy defined as the amount of heat needed to raise the temperature of 1 g of water by 1°C.

capillary wave. Small ocean wave that has a wavelength less than 1.5 cm. The primary restoring force for capillary waves is surface tension.

carbonate compensation depth (CCD). Depth below which all calcium carbonate particles falling from above are dissolved before they can be incorporated in the sediments.

carcinogens (adj. **carcinogenic)**. Compounds that cause cancer in animals. Compare *mutagens* and *teratogens*.

carnivores (adj. **carnivorous)**. Animals that depend solely on other animals for their food supply. Compare *herbivores* and *omnivores*.

cartilaginous. Pertaining to vertebrate animals that have skeletons made of cartilage, a tough elastic tissue.

catadromous. Pertaining to species of fishes that are spawned at sea, migrate to a freshwater stream or lake where they live until they reach maturity, then return to sea to spawn. Compare *anadromous*.

cation. Positively charged ion. Compare *anion*.

CCD. See carbonate compensation depth.

central rift valley. Steep-sided linear valley that runs along the crest of many parts of oceanic ridges. Central rift valleys are created by pulling apart of the diverging plates.

centripetal force. Force that acts toward the center of rotation of an orbiting body and that is needed to maintain the object in its circular path and prevent it from moving off in a straight line. See **CC12**.

cephalopods. Animals belonging to the class Cephalopoda, phylum Mollusca, that have a well-developed pair of eyes and a ring of tentacles surrounding the mouth. Most have no, or an internal, shell. Cephalopods include squid, octopi, and *Nautilus*. See Appendix 3.

cetaceans. Marine mammals belonging to an order that includes whales, porpoises, and dolphins. See Appendix 3.

CFC. See chlorofluorocarbons.

chaos (adj. **chaotic)**. Apparently random behavior of systems that involve nonlinear relationships. See **CC11**.

chemosynthesis (adj. **chemosynthetic)**. Production of organic compounds from inorganic substances by use of energy obtained from the oxidation of substances such as hydrogen sulfide, ammonia, hydrogen, and methane. Compare *photosynthesis*.

chlorofluorocarbons (CFCs). Class of compounds used as refrigerants and for many other purposes. When released to the atmosphere, CFCs migrate upward to the ozone layer, where they react with ozone, reducing its concentration.

chlorophylls. Group of green pigments that are essential to algae and plants and are active in the capture of light energy for photosynthesis. See **CC14**.

chordates. Members of the animal phylum Chordata, to which mammals, reptiles, birds, fishes, and tunicates belong. See Appendix 3.

chronic toxicity. Sublethal or lethal effects due to long-term exposure of an organism to a toxic substance at concentrations below that at which the organism suffers immediate (within days or weeks) sublethal or lethal effects.

chronometer. Clock that has sufficient long-term accuracy and tolerance of motion that it can be used as a portable time standard.

climate (adj. **climatic)**. Long-term averages of weather conditions such as temperature, rainfall, and percentage cloud cover, and the distribution of these averages among the seasons at a given location.

clones. Members of a species that are genetically identical because they are asexually reproduced.

cnidarians. Members of the phylum Cnidaria, consisting of predominantly marine animals with a saclike body and stinging cells on tentacles that surround a single opening to the gut cavity. The two basic body forms are the medusa and the polyp. Medusal forms are pelagic and include jellyfish. Polypoid forms are predominantly benthic and include sea anemones and corals. Also called "coelenterates." See Appendix 3.

coast. Strip of land that extends from the shore inland to the seaward limit of terrain that is unaffected by marine processes.

coastal plain. Low-lying land next to the ocean extending inland until the first major change in the features of the terrain.

coastal-plain estuary. Estuary formed by flooding of a coastal river valley as sea level rises.

coastal upwelling. Vertical transport and mixing of deep, nutrient-rich water into the surface water mass as a result of offshore Ekman (windblown) transport of surface water.

coastal zone. Zone between the coastline and the point offshore to which the influence of freshwater runoff extends (often the shelf break). The term can also mean this area of coastal ocean plus the adjacent coast.

coastline. Landward limit reached by the highest storm waves on the shore. Compare *shoreline*.

coccolithophores. Microscopic planktonic algae surrounded by a cell wall embedded with calcareous disks called "coccoliths." See Appendix 3.

coelenterates. See *cnidarians*.

cohesive. Pertaining to the molecular force between particles within a substance that acts to hold the particles together. Cohesive particles behave as though they were sticky. See **CC4**.

colloidal. Pertaining to substances that have a particle size smaller than clay.

community. All of the organisms that live within a definable area or volume of ocean or land.

compensation depth. Depth at which algae consume oxygen for respiration at the same rate that they produce oxygen by photosynthesis.

complexed. Generally pertaining to a dissolved ion that has an association (a weak electrostatic bond) with the molecules of a polar organic substance. The association can alter the ion's solubility, bioavailability, and toxicity.

conduction (adj. **conducted)**. Transfer of heat (or electricity) through a material or between two materials in contact with each other by passing directly from one molecule to another adjacent molecule.

contaminant (v. **contaminate)**. Substance added to an ecosystem (or to a sample, an organism, or other object) in an amount that causes the concentration of the substance to exceed its natural range of levels Contaminants may or may not have harmful effects. Compare *pollution*.

continental collision plate boundary. Region where two lithospheric plates converge, each of which has continental crust at its margin.

continental divergent plate boundary. Region where a continent is splitting apart to form the edges of two new lithospheric plates.

continental drift. Movement of the continents over the Earth's surface. Continental drift is the theory that preceded plate tectonics.

continental margin. Zone of transition from a continent to the adjacent ocean basin. The continental margin generally includes a continental shelf, continental slope, and continental rise and often the land adjacent to the coast.

continental rise. Gently sloping seafloor between the base of a continental slope and the abyssal plain. A part of the deep-ocean floor.

continental shelf. Zone bordering a continent that extends from the low-water line to the depth at which there is a marked increase in the downward slope of the seafloor that continues to the deep-ocean floor.

continental slope. Relatively steeply sloping seafloor seaward of the continental shelf that ends where the downward slope markedly decreases at the edge of the deep-ocean floor.

contour (adj. **contoured)**. Line on a chart or graph that connects points of equal value of the parameter charted (e.g., ocean depth, temperature, salinity).

convection (v. **convect,** adj. **convective)**. In a fluid being warmed at its bottom and/or cooled at its upper surface, process by which warmer fluid rises and cooler fluid sinks in a density-driven circulation. See **CC1**, **CC3**.

convection cell. Circulatory system established by convection in which water (or other fluid) is warmed, rises, is displaced by newly upwelled warm water, cools, and sinks to be warmed again. See **CC3**.

convergence (v. **converge,** adj. **convergent)**. Location at which fluids of different origins come together, usually horizontally (often in a convection cell). Convergence results in sinking (downwelling) or rising (upwelling) when it is at the top or bottom surface of a fluid layer, respectively. See **CC3**. Compare *divergence*.

convergent plate boundary. Lithospheric plate boundary where the relative motion of adjacent plates is toward each other, producing ocean trench/island arc systems or ocean trench/continental mountain and volcano complexes. Compare *divergent plate boundary*.

copepods. Small shrimplike animals of the subphylum Crustacea that are zooplankton. See Appendix 3.

corals. Group of benthic cnidarians that exist as individuals or in colonies and may secrete external skeletons of calcium carbonate. See Appendix 3.

coral reef. Mainly calcareous reef composed substantially of coral, coralline algae, and sand. Coral reefs are present only in waters where the minimum average monthly temperature is 18°C or higher.

Coriolis effect. Apparent deflection of a freely moving object caused by the Earth's rotation. The deflection is *cum sole*. See **CC12**.

cosmogenous. Pertaining to material that originated in outer space (e.g., meteorite fragments). The term is generally applied to particles of such origin within sediments. Compare *biogenous*, *hydrogenous*, and *lithogenous*.

countershading. Coloration of pelagic fishes, in which the upper half is dark and nonreflective and the lower half is light-colored and more reflective. Countershading reduces visibility to predators from above and below.

covalent bond. Chemical bond in which atoms are combined to form compounds by sharing one or more pairs of electrons.

crest. For a wave, the portion that is displaced above the still-water line. The term is often used to refer to the highest point of the wave (or other topographic feature) only. Compare *trough*.

crinoids. Animals of the class Crinoidea, phylum Echinodermata. Also called "feather stars." See Appendix 3.

crust. Outer shell of the solid Earth. The lower limit of the crust is usually considered to be the Mohorovi˘ci´c discontinuity (top of the asthenosphere). The thickness of the crust ranges from about 6 km beneath the oceans to 30 to 40 km beneath the continents. Compare *mantle*.

crustaceans. Animals of a subphylum (Crustacea) of the phylum Arthropoda that have paired, jointed appendages and hard outer skeletons. Crustaceans include barnacles, copepods, lobsters, crabs, and shrimp. See Appendix 3.

CTD. Abbreviation for conductivity, temperature, and depth. A CTD is an instrument package that measures these parameters continuously while being lowered and raised through the water column.

ctenophores. Animals of the phylum Ctenophora of transparent planktonic animals that are spherical or cylindrical in shape and have rows of cilia. Ctenophores include comb jellies. See Appendix 3.

cum sole. Literally translated from Latin as "with the sun." To the right in the Northern Hemisphere and to the left in the Southern Hemisphere. If you are facing toward the sun's arc in the sky (toward the equator), the sun appears to move from left to right in the Northern Hemisphere and from right to left in the Southern Hemisphere.

current. Horizontal movement of water.

cyanobacteria (sing. **cyanobacterium;** adj. **cyano-bacterial)**. Phylum of organisms within the domain Bacteria. Cyanobacteria were originally called "bluegreen algae" because they have the ability to photosynthesize. See Appendix 3.

cyclonic. Pertaining to counterclockwise circulation in the Northern Hemisphere and clockwise circulation in the Southern Hemisphere.

cyst. Saclike structure. Sometimes, a protective covering of a microorganism during a metabolic resting phase.

DDT. Dichloro-diphenyl-trichloroethane. Insecticide widely used in the United States in the 1950s and 1960s. DDT caused major damage to birds and marine mammal populations. It is now banned in many countries, but it is still widely used in the tropics.

declination. Measure of the sun's (or moon's) apparent north–south seasonal movement. The angle between a line from the Earth's center to the sun (or moon) and the plane of the equator.

decomposers. Heterotrophic microorganisms (mostly bacteria and fungi) that break down nonliving organic matter to obtain energy. During decomposition, nutrients are released to solution and become available for reuse by autotrophs.

deep-water wave. Ocean wave that is traveling in water depth greater than one-half its wavelength. Compare *intermediate wave* and *shallow-water wave*.

delta. Low-lying deposit of river-borne sediment at the mouth of a river. Deltas are usually triangular in shape.

density, absolute. The mass per unit volume of a substance (usually expressed as grams per cubic centimeter). Compare *density, relative*.

density, relative. The ratio of the mass per unit volume of the substance divided by the mass of the same volume of a standard substance. The standard substance is usually pure water at 4°C. Relative density is a dimensionless number, but since the mass of 1 cm3 of pure water at 4°C is almost precisely 1 g, relative density and absolute density are numerically almost identical. Compare *density, absolute*.

deposit feeders (adj. **deposit-feeding)**. Organisms that feed by ingesting particles of sediment and metabolizing organic matter in or on the particles.

deposition (adj. **depositional)**. Accumulation of sediment on the seafloor (or of solid particles from the atmosphere onto the land or ocean surface).

deoxygenation. Reducing the concentration of dissolved oxygen. Applied to oceans refers to the lowering of dissolved oxygen in deep waters due to anthropogenic influences including excessive nutrient inputs, and climate change induced increased surface layer temperature that leads to higher primary production and a strengthened pycnocline that slows deep ocean water circulation. May lead to hypoxia and anoxia.

detritivores (adj. **detritivorous)**. Organisms that eat organic detritus.

detritus. Any loose material, but generally decomposed, broken, and dead organisms.

diagenesis (adj. **diagenetic)**. Chemical or mineralogical changes that take place in a sediment or sedimentary rock after its formation.

diatoms. Microscopic unicellular algae of the phylum Chrysophyta that have an external skeleton of silica. See Appendix 3.

diffusion (v. **diffuse)**. Movement of a substance (or property such as heat) by random molecular motions from a region of higher concentration to a region of lower concentration (along a concentration gradient).

dinoflagellates. Single-celled microscopic organisms in the kingdom Protista. Dinoflagellates may have chlorophyll, be autotrophic, and belong to the phylum Pyrrophyta; or they may be heterotrophic and belong to the phylum Zoomastigophora. See Appendix 3.

dip angle. Angle to the horizontal of the direction of the magnetic field in rock. The dip angle is approximately equal to the latitude at which the rock formed.

diurnal. Having a cycle that occurs during a 24-h day and that generally recurs daily.

diurnal tide. Tide with one high water and one low water during a tidal day (approximately 24 h 49 min). Compare *semidiurnal tide* and *mixed tide*.

divergence (v. **diverge,** adj. **divergent)**. Horizontal flow of a fluid away from a common center. The fluid is replaced by upwelling if the divergence is at the surface of the fluid and by downwelling if it is at the bottom. Compare *convergence*.

divergent plate boundary. Lithospheric plate boundary where adjacent plates are pulling apart from each other. Compare *convergent plate boundary*.

diversity (adj. **diverse)**. Presence of variety or variation within an ecosystem. The term may be applied to variety of species, variety of genes within a species, variety of habitat, etc. See CC17.

DNA. Deoxyribonucleic acid. Complex organic molecule that contains the genetic code.

downwelling (adj. **downwelled)**. Vertical movement of a fluid downward due to density differences or where two fluid masses converge, displacing fluid downward. In the ocean, the term often refers to coastal downwelling, where Ekman transport causes surface waters to converge or impinge on the coast, displacing surface water downward and thickening the surface layer. Compare *upwelling*.

drift net. Net hung vertically like a drape that may extend for many kilometers. Drift nets indiscriminately catch anything that swims into them.

dynamic height. Height of the water column above a depth below which no currents are assumed to be present.

eastern boundary current. Surface layer current that flows toward the equator on the eastern side of a subtropical gyre. Eastern boundary currents are slow, wide, and shallow. Compare *western boundary current*.

ebb. Period of a tidal cycle when the tidal current is flowing seaward or when the tide level is falling. Compare *flood*.

echinoderms. Animals of the phylum Echinodermata, which have bilateral symmetry in larval forms and usually a five-sided radial symmetry as adults. Echinoderms are benthic organisms with rigid or articulating external skeletons of calcium carbonate that have spines. Echinoderms include sea stars, brittle stars, sea urchins, sand dollars, sea cucumbers, and sea lilies. See Appendix 3.

echolocation. Use of sound by some marine animals to locate and identify underwater objects from their echoes.

ecology (adj. **ecological)**. Study of relationships between species and between the species and their environment.

ecosystem. Organisms in a community and the nonliving environment with which they interact.

eddy. Circular movement of water.

EEZ. See exclusive economic zone.

effluent. Outflow of water from a system. The term is often applied to wastewater discharges that flow out of a treatment plant, sewer, industrial outfall, or storm drain.

Ekman transport. Net wind-driven transport of surface water at an angle *cum sole* to the wind direction as a result of the Coriolis effect.

El Niño. Episodic movement of warm surface water south along the coast of Peru that is associated with the cessation of upwelling in this region. The term is often used to refer to a complex episodic sequence of events in the oceans and atmosphere called "El Niño/Southern Oscillation" (ENSO).

electrical conductivity. Measure of a substance's ability to conduct an electrical current. In seawater, electrical conductivity is related to (and used to measure) salinity.

electromagnetic radiation. Energy that travels at the speed of light as waves. Electromagnetic waves range in wavelength from very long (up to 10 km) radio waves to very short (10^{-12} m) cosmic rays.

electrostatic. Pertaining to the attractive or repulsive force between two electrically charged bodies that does not involve electrical current flow between the bodies.

embryo. Early or undeveloped life stage of an animal.

emission spectrum (pl. **spectra)**. Wavelengths at which warm bodies emit electromagnetic energy. Emission spectra are

plotted as the relative intensity of emission versus wavelength. Emission spectra vary with an object's temperature. Compare *absorption spectrum*.

encrust. To grow on the surface of and form a crust on a solid substrate.

ENSO. El Niño/Southern Oscillation. See *El Niño*.

environment. Physical and chemical characteristics of a location or area.

enzymes. Organic substances that are synthesized by organisms and behave as catalysts for biochemical reactions.

epifauna. Animals that live on the surface of the seafloor or other substrate, either moving freely or attached. Compare *infauna*.

epipelagic zone. Upper region of the oceanic province. The water column from the surface to a depth of 200 m.

equinox. Time of year when the sun is directly overhead at the equator. Equinoxes occur on March 20 or 21 and September 22 or 23 each year. Compare *solstice*.

erosion (v. **erode,** adj. **erosional)**. Process of being gradually worn away. Erosion is usually caused by the action of winds and currents on rocks and sediments.

estuary (adj. **estuarine)**. Any region where freshwater and seawater mix.

eukaryotes. Organisms (single-celled or multi-celled) whose cells are surrounded by a membrane and that have a structurally discrete nucleus and other well-developed subcellular compartments. Eukaryotes include all organisms except archaea, and bacteria. Compare *prokaryotes*.

euphausiids. Members of an order of shrimplike planktonic animals of the subphylum Crustacea, phylum Arthropoda. Euphausiids include several species commonly called "krill." See Appendix 3.

eustasy (adj. **eustatic)**. The equilibrium level of the ocean surface. Eustatic changes of sea level take place in response to changes in ocean volume and take place worldwide, as distinct from locally. See **CC2**.

eutrophication. Physical and biological changes that occur when excessive nutrients are released into an aquatic environment. Eutrophication may lead to blooms and anoxia.

evaporite. Mineral deposit formed by the evaporation of seawater.

exclusive economic zone (EEZ). Zone in which the coastal state (nation) has ownership of resources including fishes and seafloor minerals. EEZs are generally 200 nautical miles (370 km) wide.

excretion (v. **excrete)**. Substances (generally waste products) released to the external environment from the tissues of a living organism, or the process of releasing such substances.

excurrent. In animals that feed by pumping or passing water through the body (e.g., tunicates), pertaining to the opening through which the ingested water is expelled from the organism. Compare *incurrent*.

exotic terrane. Fragments of continental crust or sometimes oceanic crust and sediment that have been accreted (attached) to other continents.

extratropical cyclone. Cyclonic storm formed in high latitudes at the polar fronts. Extratropical cyclones resemble and can be as strong as hurricanes.

family. Level of taxonomic classification of species that is between the levels of order and genus. See Appendix 3.

fault. Fracture in the Earth's crust in which one side has been displaced in relation to the other.

fauna. Animal population of an ecosystem or region. Compare *flora*.

fecal pellet. Solid waste product excreted by animals.

feedback. Reaction to a process of change that either reinforces or moderates that change. See **CC9**.

fetch. Uninterrupted distance over which the wind blows (measured in the direction of the wind) without a significant change of direction.

filter feeders (adj. **filter-feeding)**. Animals that feed by sifting or straining small particles suspended in the water. Compare *suspension feeders*.

fjord. Long, narrow, deep inlet. Usually the seaward end of a valley flooded by rising sea level after it was cut by a glacier that has since retreated.

flagellates. Protozoa that have flagella. See Appendix 3.

flagellum (pl. **flagella)**. Whiplike appendage used by some microscopic organisms to provide propulsion for locomotion.

flood. Period of a tidal cycle when the tidal current is flowing landward or when the tide level is rising. Compare *ebb*.

flora. Plant population of an ecosystem or region. Compare *fauna*.

focus. Location within the Earth's crust where an earthquake occurs.

food chain. Sequence of organisms in which each is the food source for the next in sequence. Compare *food web*.

food chain efficiency. Percentage of food ingested by organisms at a particular trophic level that is converted into biomass at that trophic level. Also called "trophic efficiency." See **CC14**.

food web. Series of food chains that are interconnected in a complex way to create a mosaic of feeding relationships.

foraminifera (sing. **foraminiferan;** adj. **foraminiferal)**. Planktonic and benthic protozoa of the phylum Sarcodina, protected by shells, and usually calcareous. See Appendix 3.

foreshore. Zone between the low- and high-tide lines. Compare *backshore*.

fossil. Remains of an organism or its imprint that has been preserved in rocks.

fossil fuel. Fuel that is derived directly from fossilized organic matter. Fossil fuels include oil, natural gas, coal, and peat.

foul (n. **fouling)**. To attach to or lie on the surface of an underwater object. The term applies especially to barnacles and other marine organisms that grow on vessel hulls and other human-made structures.

fracture zone. Linear zone of steep-sided irregular seafloor topography. Most fracture zones are inactive remnants of transform faults.

frequency. Number of periodic events that occur within a specified interval. For waves, the number of crests (or troughs) that pass a given point per unit time; the inverse of wave period.

friction. Retarding force that resists the motion of two objects (or an object and a fluid, or two fluids; see *shear stress*) that are moving in relation to each other and whose surfaces are in contact.

fringing reef. Reef that is attached to the shore of an island or continent with no open water lagoon between the reef and shore. Compare *barrier reef* and *atoll*.

front. Well-defined boundary between two air masses or two water masses of different density.

frustule. Siliceous covering of a diatom.

fundamental niche. Range of environmental variables within which a species can both survive and successfully reproduce. Compare *survival niche*.

fungi. Members of the kingdom Fungi, organisms that reproduce by means of spores. Most marine fungi are microscopic benthic decomposers. See Appendix 3.

galaxy (adj. **galactic)**. Assemblage of stars (millions to hundreds of billions) held together by the gravitational attraction of the member stars on one another. Most galaxies are either a flattened, spiral form like the Milky Way, the galaxy in which our sun is located, or elliptical without a spiral pattern.

genetic. Pertaining to the genes of an organism. The term refers to the information (genetic code) encoded in DNA and other substances that describes the characteristics of an organism and that can be passed on to the offspring during reproduction.

genus (pl. **genera)**. Level of taxonomic classification of species that is between the levels of family and species. See Appendix 3.

geostrophic. Pertaining to cyclonic fluid motions that are maintained as a result of a near balance between a gravity-induced horizontal pressure gradient and the Coriolis effect. See **CC13**.

gill. Thin-walled organ of marine animals used for respiration.

glaciation. Extent to which glaciers are developed in a given area or at a given time.

glacier (adj. **glacial)**. Large mass of ice that forms on land by the recrystallization of old compacted snow. Glaciers flow from the area where they are formed downhill to an area where ice is removed by melting or calving (breaking off) into a water body.

gobies. Members of a family of small bony fishes (class Ostreichthyes, subphylum Vertebrata, phylum Chordata). Many goby species have pelvic fins modified to form a suction disk. See Appendix 3.

graded bed. Vertical sequence of sediments or sedimentary rock in which each layer comprises particles of smaller grain size from bottom to top.

grain size. Diameter of grains that compose a sediment.

gravity. Attractive force between any two bodies in the universe.

grazers (v. **graze)**. Strictly, animals that eat plants or algae. More generally, the term includes animals that eat detritus (or other animals) that covers the surface of a substrate.

greenhouse effect. Tendency of the atmosphere or greenhouse glass to be transparent to incoming solar radiation while absorbing (or reflecting) longer-wavelength heat radiation from the Earth. See **CC9**.

groin. Artificial structure that projects into the ocean from the shore. Groins block longshore transportation of sediment and usually are intended to trap sand and prevent its loss from a beach.

groundwater. Water beneath the ground surface that has seeped through the soil and rock from above.

guyot. Conical, volcano-shaped feature on the ocean floor whose top has been eroded to form a flat top.

gyre. Circular motion. The term generally refers to a circular current system centered in the subtropical high-pressure region of a major ocean basin.

habitat. Place where a particular organisms lives.

hadal zone. Deepest environment of the oceans. Restricted to ocean trenches deeper than 6 km.

half-life. Amount of time required for half the atoms of a radioactive isotope sample to decay to atoms of another element. See **CC7**.

halocline. Depth range in the water column in which there is a gradient of salinity in the vertical dimension. Compare *pycnocline* and *thermocline*.

hard parts. Rigid structural material of plants and algae and the shells and skeletons of animals. Hard parts are usually siliceous or calcareous.

harmonics. Component simple waves that are added together to make up the complex waveform observed as a result of the interference of waves of different frequencies and/or from different directions.

heat capacity. Amount of heat required to raise the temperature of 1 g of a substance by 1°C.

herbicides. Chemicals that are used to kill or inhibit the growth of plants.

herbivores (adj. **herbivorous)**. Animals that rely primarily or solely on plants, algae or photosynthetic bacteria for their food. Compare *carnivores* and *omnivores*.

hermatypic corals. Reef-building corals that have symbiotic algae in their tissues and that cannot grow successfully below the photic zone.

hermit crabs. Any of a number of species of crabs of the suborder Reptantia, order Decapoda, subphylum Crustacea, phylum Arthropoda that have no shell of their own. Hermit crabs live in shells of dead gastropod mollusks and move to a larger shell as they grow. See Appendix 3.

herrings. Members of a family of small plankton-eating bony fishes (class Ostreichthyes, subphylum Vertebrata, phylum Chordata) that have oily tissues and are extremely abundant in some areas. Herrings include sardines and anchovies. See Appendix 3.

heterotrophs (adj. **heterotrophic)**. Animals or bacteria that do not photosynthesize or chemosynthesize and therefore depend for food and energy on organic compounds produced by other species. Compare *autotrophs*.

high seas. Area of the world oceans that is outside the territorial control of any nation.

high-tide line. Highest point on the shore that is covered by water at high tide. Compare *low-tide line*.

high-tide zone. Zone of the shore that is mostly exposed and lies between the lowest (neap) high-tide line and highest (spring) high-tide line. Compare *low-tide zone* and *middle-tide zone*.

holoplankton. Organisms that spend their entire life as members of the plankton. Compare *meroplankton*.

hot spot. Surface expression of a persistent convection plume of molten mantle material rising to the Earth's surface.

humidity. Amount of water vapor in the air. It is measured as relative humidity, the ratio of the water vapor concentration to the saturation concentration at the same temperature and pressure, expressed as a percentage.

hurricane. Tropical cyclonic storm with winds that have velocity greater than 120 $km \cdot h^{-1}$. The term applies to such storms in the North Atlantic Ocean, eastern North Pacific Ocean, Caribbean Sea, and Gulf of Mexico. Such storms in the western Pacific Ocean are known as "typhoons," "cyclones," or "willy willys."

hydrated (n. **hydration)**. Chemically combined with water or,

for ions, surrounded by water molecules in a weak electrostatic association.

hydrocarbons. Large group of chemicals containing carbon and hydrogen atoms. The carbon atoms may be arranged in chains of varying length or in one or more six-atom rings. These compounds are the predominant components of petroleum, and some are also produced by plankton.

hydrogen bond. Bond between molecules that forms because of the dipolar nature of the molecules. Hydrogen bonds are present in water and a few other compounds.

hydrogenous. Pertaining to solid material formed by chemical precipitation from solution. The term usually applies to the component particles or coatings of sediments that are precipitated from seawater. Compare *biogenous*, *cosmogenous*, and *lithogenous*.

hydrographic. Pertaining to mapping of the oceans and their depth.

hydroids. Group of animal species of the class Hydrozoa, phylum Cnidaria. Polypoid forms attach to the substrate. Most are colonial, many with a branching form resembling a feather or fern on which individual polyps are arranged. Hydroids reproduce by budding and have a pelagic medusal stage. See Appendix 3.

hydrophone. Device that senses underwater sound.

hydrosphere. Gaseous, liquid, and solid water of the Earth's upper crust, ocean, and atmosphere. The hydrosphere includes lakes, groundwater, snow, ice, and water vapor.

hydrostatic pressure. Pressure that results from the weight of the water column that overlies the depth at which the pressure is measured.

hydrothermal minerals. Predominantly fine-grained particles precipitated from the water that is discharged at hydrothermal vents. Hydrothermal minerals are rich in iron and manganese.

hydrothermal vent. Location where heated water is vented through the seafloor. This water is seawater that has percolated down through fractures in recently formed ocean floor and has been heated by underlying magma. Most known vents are near the central axis of oceanic ridges and rises.

hypoxia (adj. **hypoxic)**. Presence of dissolved oxygen in the aquatic environment at concentrations low enough to be detrimental to organisms. Hypoxia is usually considered to exist when dissolved oxygen concentrations are at or below 2 mg·l–1. Compare *anoxia*.

ice age. Period during which the Earth's average climatic temperature was colder, glaciers were more extensive, and sea level was lower. Several such periods have occurred in the past million years, each lasting for several thousand years.

ice exclusion. Process whereby salts are excluded from the ice that forms as seawater freezes, resulting in a higher salinity in the remaining liquid water.

in situ. Literally translated from Latin as "in place"—that is, not removed from its natural environment.

incubation. Maintenance of eggs or embryos in a favorable environment for hatching and development.

incurrent. In animals that feed by pumping or passing water through the body (e.g., tunicates), pertaining to the opening through which the ingested water is taken into the organism. Compare *excurrent*.

infauna. Animals that live buried in soft sediments (sand or mud). Compare *epifauna*.

intermediate wave. Surface water wave that, at a given water depth, has a wavelength between those of deepwater waves and shallow-water waves. Wave in water depth between one-half and one-twentieth of the wavelength. Compare *deep-water wave* and *shallow-water wave*.

internal wave. Wave that develops below the surface of a fluid at a pycnocline and travels along this boundary.

intertidal zone. Zone covered by the highest normal tides and exposed by the lowest normal tides, and any tide pools within this zone. Also called "littoral zone."

intertropical convergence. Zone where northeast trade winds and southeast trade winds converge.

invertebrates. Animals that have no backbone.

ion (adj. **ionic)**. Atom (or combined group of atoms) that becomes electrically charged by gaining or losing one or more electrons to produce a negatively charged anion or a positively charged cation, respectively.

ionic bond. Chemical bond that is formed by the electrical attraction between cations and anions.

isobar (adj. **isobaric)**. Line that connects values of equal pressure on a map or graph. Compare *isopycnal* and *isotherm*.

isopods. Animals with flattened bodies belonging to an order of the phylum Crustacea. Most isopods are scavengers or parasites on other crustaceans or fishes. See Appendix 3.

isopycnal. Line that connects values of equal density on a map or graph. Compare *isobar* and *isotherm*.

isostasy (adj. **isostatic)**. Equilibrium, comparable to buoyancy, in which the rigid lithospheric plates float on the underlying mantle. See **CC2**.

isostatic leveling. Tendency of lithospheric plates to rise or fall to an equilibrium level with respect to the level at which they float on the asthenosphere after their density or mass has changed—for example, after cooling of the crust or changes in the extent of glaciation. See **CC2**.

isotherm. Line that connects points of equal temperature on a graph or map. Compare *isobar* and *isopycnal*.

isothermal. Of the same or uniform temperature.

isotope (adj. **isotopic)**. Atoms of an element that have different numbers of neutrons, and therefore different atomic masses than the atoms of other isotopes of the same element. See **CC7**.

jet stream. Easterly-moving air mass at an altitude of about 10 km that can have speeds exceeding 300 km·h–1. Jet streams follow a meandering path in the mid latitudes and influence how far polar air masses extend into lower latitudes.

jetty. Elongated structure built outward from the shore into a body of water to protect a harbor or a navigable passage from accumulation of sand transported by longshore drift.

joule. Unit of energy equal to the energy expended in 1 s by an electrical current of 1 ampere with a potential difference of 1 volt.

kelp. Various species of large brown algae (Phaeophyta). See Appendix 3.

kinetic energy. Energy of an object in motion. Kinetic energy increases as the mass of the object or the speed of the object in motion increases. Compare *potential energy*.

krill. Common name applied to euphausiids, members of an order of the subphylum Crustacea, phylum Arthropoda. See Appendix 3.

lagoon. Shallow estuary or area of ocean adjacent to the shore

but partly or completely separated from the open ocean by an elongated, narrow strip of land such as a reef or barrier island.

Langmuir circulation. Cellular water circulation set up by strong winds that blow consistently in one direction. The cells are arranged in alternating clockwise and counterclockwise helical spirals aligned parallel to the wind direction.

larva (pl. **larvae)**. Animal embryo that lives free from its parents before assuming the adult form.

laser. Abbreviation for "light amplification by stimulated emission of radiation." Instrument that generates a very intense, extremely narrow beam of light of a single wavelength.

latent heat of fusion. For 1 g of a substance at its melting point temperature, the quantity of heat energy that must be added to convert it from solid to liquid (or that must be removed to convert the liquid to solid) without changing the temperature.

latent heat of vaporization. For 1 g of a substance at its boiling point temperature, the quantity of heat energy that must be added to convert it from liquid to gas (or that must be removed to convert the gas into liquid) without changing the temperature or pressure.

latitude (adj. **latitudinal)**. Partial designation of location on the Earth's surface. Latitude is expressed as the angular distance north or south of the equator. The equator has a latitude of 0°, the North Pole 90°N, and the South Pole 90°S. Compare *longitude*.

lava. Fluid magma that emerges from an opening in the Earth's surface, or the same material after it cools and solidifies.

leach (v. **leaching)**. To dissolve constituents of solids by passing (filtering) a fluid (usually water) through cracks or pores in the solid or sediment.

leeward. The direction toward which the wind is blowing or the waves are moving. The term usually applies to the sheltered downwind or downcurrent side of a barrier or landmass. Compare *windward*.

levee. Low ridge that forms the sides of a river channel. Levees may be human-made or natural (created by sediment deposition during flooding).

lichens. Organisms that are a mutualistic relationship of fungi with algae or cyanobacteria. The algae (or cyanobacteria) are protected by the fungi, which depend on the algae to produce food by photosynthesis. See Appendix 3.

light-limited. Pertaining to the condition in which the rate of production of organic matter by a photosynthetic organism or population of organisms is inhibited by the absence of sufficient light energy when all other requirements for an increase in the rate of production are met.

limestone. Sedimentary rock composed of at least 50% calcium or magnesium carbonate. Limestone may be either biogenous or hydrogenous.

limiting nutrient. Nutrient present at such a low concentration that its lack of availability reduces the rate of growth or prevents the growth of phytoplankton (or other primary producers).

limpets. Mollusks of the class Gastropoda, phylum Arthropoda, that have a low conical shell and adhere to a substrate where they are covered by the shell. See Appendix 3.

lipids. Fats. Lipids are among the principal structural components of living cells.

lithogenous. Pertaining to material derived from the rock of continents and islands and transported to the ocean by wind or running water. The term is usually applied to sediments that have a high proportion of mineral grains of terrestrial origin. Compare *biogenous*, *cosmogenous*, and *hydrogenous*.

lithosphere (adj. **lithospheric)**. Outer layer of the Earth. The lithosphere includes the crust and the part of the upper mantle that is fused to the crust. It is the layer that is broken into the lithospheric plates.

lithospheric plates. Sections of the Earth's lithosphere that are separated from each other by boundaries at which the adjacent sections move in relation to each other.

littoral drift. See *longshore drift*.

littoral zone. To biological oceanographers, the benthic zone between the highest and lowest normal water marks reached by the tide. To geological oceanographers, the zone between the seaward boundary of land vegetation (or the base of a cliff if present) and the point where the seafloor reaches a depth at which sediment is no longer disturbed by waves.

longitude (adj. **longitudinal)**. Partial designation of location on the Earth's surface. Longitude is expressed as the angular distance east or west of the Greenwich meridian (0° longitude). 180° longitude is the international date line. Compare *latitude*.

longshore bar. Sand mound that extends generally parallel to the shoreline a short distance offshore. The bar may be submerged or exposed, especially at low tide, and is created by sand accumulated by wave action.

longshore current. Current that flows in the surf zone and parallel to the shore. Longshore currents are created by breaking waves.

longshore drift. Sediment transport along the beach within the region from the breaker zone to the top of the swash line. Longshore drift is associated with the long-shore current. Also called "littoral drift."

low-tide line. Lowest point on the shore that is not covered by water at low tide. Compare *high-tide line*.

low-tide terrace. Flat section of the foreshore that lies seaward of any scarp and on which most wave energy is dissipated.

low-tide zone. Zone of the shore that is mostly covered with water and lies between the highest (neap) low-tide line and the lowest (spring) low-tide line. Compare *high-tide zone* and *middle-tide zone*.

lunar month. Interval between successive times when the moon and sun are both directly overhead at a specific line of longitude at a specific time of day. The time interval between two successive full moons (or new moons), approximately 291/2 days.

macroalgae (sing. **macroalga)**. Algae that have massive forms, easily seen by the naked eye. Macroalgae are generally attached to the substrate. Compare *microalgae*.

magma. Molten rock.

magmatic arc. Line of volcanic islands formed on the nonsubducting plate parallel to and near an oceanic convergent plate boundary.

magnetic anomaly. Local variation of the Earth's magnetic field caused by variable magnetization of minerals in the Earth's crust.

manganese nodule. Lump of hydrogenous mineral consisting primarily of oxides of iron and manganese. Manganese nodules are scattered in groups over some parts of the ocean floor.

mangrove. Group of tropical plant species that grow in low

marshy areas at latitudes below about 30°. Mangroves have extensive root systems and produce much organic detritus to create a unique coastal environment for marine life.

mantle. 1. The layer of the Earth between the core and crust. 2. In certain mollusks, including clams, mussels, and oysters, the part of the animal's body that secretes shell materials.

marginal sea. Semi-enclosed body of water adjacent to a continent.

marine mammals. Members of the class Mammalia, subphylum Vertebrata, phylum Chordata, that live some or all of their life in the ocean. Warm-blooded animals that have mammary glands and hair, and that bear live young. See Appendix 3.

maximum sustainable yield. Maximum quantity of fish that can be harvested annually while still allowing the population to be sustained by reproduction. See **CC16**.

meander (adj. **meandering)**. Sinuous curve or turn in a current (of any fluid such as air, river water, ocean water, or magma).

meroplankton. Planktonic larval forms of organisms that become members of the benthos or nekton when they become adult. Compare *holoplankton*.

mesoplates. Hypothesized segments of the Earth's mid-depth mantle that may move relative to each other below the crustal tectonic plates. Three major mesoplates have been proposed: Hawaiian (mostly beneath the oceanic plates of the Pacific), Tristan (beneath most plates of the Atlantic and Indian Oceans), and Icelandic (beneath Eurasia, the northernmost Atlantic Ocean, and the Arctic Ocean).

metamorphosis (v. **metamorphose)**. 1. Change of form of an organism, usually as it passes from one life stage to another, similar to the change from caterpillar to butterfly. 2. Change in the mineral composition of rocks after their initial formation.

methane hydrates. Ice-like solids formed in sediments or sedimentary rock layers by the trapping of methane gas in the crystalline lattice of water at high pressures and low temperatures. At atmospheric pressure, they are unstable and release their methane.

microalgae (sing. **microalga)**. Algae that are sufficiently small that they cannot be seen easily by the naked eye unless present in high concentrations. Most microalgae are single-celled, and they may be benthic or planktonic. Compare *macroalgae*.

microbial. Organisms too small to be seen with the naked eye (about 1mm or 100µm).

micronutrient. An element or compound, including certain trace metals and vitamins, that is essential to the life processes of some species of organisms and that is present in seawater at concentrations substantially lower than those of nitrogen and phosphorus compounds.

middle-tide zone. Zone between the high-tide zone and the low-tide zone that is usually covered by water but is exposed to the atmosphere during all or most low tides.

mixed layer. Surface layer of ocean water that is mixed by wave and tide motions. As a result of the mixing, this layer has relatively uniform temperature and salinity.

mixed tide. Tide that has two high and two low tides each tidal day, with the two highs and/or the two lows being markedly different in height. Compare *diurnal tide* and *semidiurnal tide*.

mole. SI unit for the amount of substance (abbr. mol). Measure of the amount of substance which contains the same number of atoms, molecules, or ions. The mass (weight) of a substance divided by the substances molecular weight.

molality. Concentration of a dissolved substance in moles per kiogram of solvent. See **mole**

molarity. Concentration of a dissolved substance in moles per liter of solvent. See **mole**

mollusks. Members of a phylum (Mollusca) of soft unsegmented animals that usually are protected by a calcareous shell and use a muscular foot for locomotion. Mollusks include snails, mussels, clams, chitons, and octopi. See Appendix 3.

monsoon (adj. **monsoonal)**. Seasonally reversing winds, especially those in the Indian Ocean and southern Asia that blow from the southwest during summer and from the northeast during winter. The term is derived from the Arabic word for season, *mausim*.

mutagens (adj. **mutagenic)**. Chemical compounds that can cause mutations in organisms that are exposed to them. Compare *carcinogens* and *teratogens*.

neap tide. Tide that has the smallest range within a lunar month. Neap tides occur twice during the month, when the moon is at its first and third quarters. Compare *spring tide*.

nebula (pl. **nebulae)**. Cloud of interstellar gas and dust, often illuminated by stars.

nekton. Pelagic animals that are active swimmers and thus can overcome currents and determine their position in the ecosystem. Nekton include fishes, marine mammals, and squid.

niche. Range of environmental characteristics within which a particular species can survive and reproduce. The term is often used to include the function of the organism itself in the ecosystem.

node. Point on a standing wave where there is no (or minimal) vertical motion. Compare *antinode*.

nonindigenous species. Species that is imported, accidentally or deliberately, to an ecosystem in which it is not present naturally.

nonpoint source. Source of pollution other than discharge pipes of industry and sewage treatment plants. Nonpoint sources include storm drains, street runoff, runoff from agricultural land, deposition of air pollutants, acid rain, and many other widely dispersed sources.

nudibranchs. Sea slugs. Members of the class Gastropoda, phylum Mollusca, that have no protective covering as adults. See Appendix 3.

nutrient. Any organic or inorganic compound that is used by plants, algae or photosynthetic bacteria in primary production. The most important nutrients include nitrogen and phosphorus compounds.

nutrient-limited. Pertaining to the condition in which the rate of growth of an organism or population of organisms, generally the production of organic matter by a photosynthetic organism or populations of organisms, is inhibited by the absence of a sufficient supply of one nutrient element (often nitrogen or phosphorus) when all other requirements for an increase in the rate of growth or production are met.

oceanic convergent plate boundary. Region where two lithospheric plates converge, each of which has oceanic crust at its margin. Compare *oceanic ridge*.

oceanic plateau. Small area where the seafloor is raised a kilometer or more above the surrounding oceanic crust. Oceanic plateaus are extinct volcanoes, old oceanic ridges, or fragments of continents.

oceanic ridge. Linear undersea mountain range that marks a tectonic plate boundary where two lithospheric plates diverge. Oceanic ridges extend through all the major oceans. Compare *oceanic convergent plate boundary*.

omnivores (adj. **omnivorous)**. Animals that feed on both on other animals and plants, algae or photosynthetic bacteria. Compare *carnivores* and *herbivores*.

ooze. Sediment that contains at least 30% skeletal remains of marine organisms. Ooze may be siliceous or calcareous, and it may be diatom ooze, foraminiferal ooze, radiolarian ooze, or pteropod ooze, depending on the organisms that are the major contributors to the sediment.

orbital velocity. For an orbiting object (or particle within a wave), the speed of movement (distance covered per unit time) in the orbital path. See **CC12**.

osmoregulation. Ability of an organism to adjust its internal salt concentration independently of the external salinity.

osmosis. Passage of water molecules from a solution of lower solute concentration into a solution of higher solute concentration through a semipermeable membrane that separates the two solutions.

osmotic pressure. Measure of the tendency for osmosis to occur. The pressure that must be applied to a solution to prevent water molecules from passing into it through a semipermeable membrane that has pure water on the other side.

outfall. Pipeline that extends from the shore across the seafloor. An outfall carries liquid waste some distance offshore, where it is discharged from the submerged end of the pipe.

overfishing (adj. **overfished)**. Harvesting a fish species at a rate exceeding the maximum harvest that would still allow a stable population to be maintained by reproduction.

oviparous. Pertaining to animals that release eggs that develop and hatch outside the body. Compare *ovoviviparous* and *viviparous*.

ovoviviparous. Pertaining to animals that incubate eggs inside the reproductive tract (usually the mother's) until they hatch. Compare *oviparous* and *viviparous*.

oxygen demand (adj. **oxygen-demanding)**. Quantity of oxygen that is needed to decompose organic matter or oxidize chemicals in an ecosystem. Waste materials often increase the natural oxygen demand.

ozone. Form of oxygen in which the molecule has three oxygen atoms.

ozone layer. Region of the atmosphere between about 15 and 30 km altitude in which there is a natural high concentration of ozone. Ozone in this layer absorbs much of the ultraviolet radiation from the sun.

PAH. See polyaromatic hydrocarbons.

paleomagnetism (adj. **paleomagnetic)**. The record of the past orientation of the Earth's magnetic field incorporated in rocks during their formation.

parasites. Organisms that take their food and nutrients from the tissues of another organism. Parasites benefit from the host, but the host is disadvantaged.

parasitism. Symbiotic relationship in which the parasite harms the host from which it takes its nutrition.

partial tides. Harmonic components comprising the tide at any location. The periods of the partial tides are derived from the various components of the periodic motions of the Earth, sun, and moon in relation to one another.

partially mixed estuary. Estuary in which a distinct low-salinity layer moves seaward over a distinct higher-salinity layer that moves landward, but with a vertical gradation of salinity between the layers due to substantial vertical mixing. Compare *salt wedge estuary* and *well-mixed estuary*.

passive margin. A continental margin that is not significantly deformed by tectonic processes, because the margin is located away from the edge of a lithospheric plate.

pathogen (adj. **pathogenic)**. Any microscopic organism that causes disease.

PCBs. Polychlorinated biphenyls, a group of industrial chemicals with a variety of uses. PCBS are toxic and mutagenic, they are not readily biodegraded, and they may be biomagnified.

pelagic. Pertaining to the open-ocean water environment.

petroleum hydrocarbons. Organic compounds that are present in petroleum and that consist predominantly of carbon and hydrogen. Extremely large numbers of different compounds are present in any petroleum sample.

pH. Measure of acidity or alkalinity. pH is measured on a logarithmic scale of 1 to 14 in which lower values indicate higher hydrogen ion concentration and therefore higher acidity.

phosphorite nodule. Lump composed primarily of phosphate minerals. Phosphorite nodules are scattered throughout certain parts of the ocean floor.

photic zone. Upper part of the ocean in which solar radiation is of sufficient intensity to enable photosynthesis to occur. Compare *aphotic zone*.

photosynthesis (v. **photosynthesize,** adj. **photosynthetic)**. Production of carbohydrate from carbon dioxide and in the presence of chlorophyll or related pigments by the use of light energy (see **CC14**). Note that this text uses photosynthesis to refer broadly to a number of photoautotrophic pathways known to be important in the oceans and not the strict definition used by some biologist to refer only to the specific process that requires chlorophyll a and splits the water molecule to produce and release oxygen. Compare *chemosynthesis*.

phytoplankton. Plankton that photosynthesize. Includes algae and photosynthetic bacteria. Compare *zooplankton*.

pinnipeds. Members of a suborder (Pinnipedia) of marine mammals that includes sea lions, seals, and walrus. See Appendix 3.

planetary vorticity. Rate of rotation of a fluid (ocean water or atmospheric air) due to the rotation of the Earth.

plankton (adj. **planktonic)**. Organisms that drift passively or swim weakly and are dependent on currents to determine their location. Most plankton are microscopic forms.

plate tectonics (adj. **plate tectonic)**. Initially a theory that the lithosphere is divided into plates that are moving relative to each other across the Earth's surface. Now the term refers to the processes affecting plate motions and the effects of these motions.

pollution (v. **pollute)**. Addition of substances to or alteration of the ocean ecosystem in a way that is deleterious to the ocean ecosystem or its resources. Compare *contaminant*.

polyaromatic hydrocarbons (PAHs). Organic compounds present in organisms and petroleum, and created by the burning of fossil fuels that have carbon atoms arranged in ring structures. PAHs include the more toxic and carcinogenic compounds in petroleum.

polyp. Single individual of a cnidarian colony or a solitary at-

tached cnidarian that has a central mouth fringed with many small tentacles.

pore water. Solution present between the mineral grains of a sediment or rock.

potential energy. Energy that is the result of the relative position of an object, such as the energy of a compressed coil spring or of an object that is placed at the top of a slope. In each case, the potential energy can be released and converted to kinetic energy by releasing the object.

pressure gradient. Pressure (P) variation on a horizontal surface. A gradient can be straight or curved. The steepness of the gradient is measured as difference in pressure per unit distance within the gradient (e.g., $\delta P \cdot km^{-1}$).

primary production. The process of synthesis of organic material by photosynthetic or chemosynthetic autotrophs. The term is sometimes used to mean primary productivity.

primary productivity. Rate of production of organic matter by autotrophs, measured as the quantity (usually mass) of organic matter synthesized by organisms from inorganic substances within a given volume of water or other habitat in a unit of time.

progressive wave. Wave in which the waveform progressively moves. Compare *standing wave*.

prokaryotes. Organisms (single-celled or multicelled) whose cells are not surrounded by a membrane and that do not have a discrete nucleus and other subcellular compartments. Archaea and bacteria are prokaryotes. Compare *eukaryotes*.

protists. Members of the kingdom Protista. Protists are those eukaryotes that are not animals, plants, or fungi.

protozoa (s. **protozoan)**. Single-celled animals that have a nucleus confined within a membrane. See Appendix 3.

pteropods. Members of an order of pelagic animals of the class Gastropoda, phylum Mollusca, in which the foot is modified for swimming and the shell may be absent. See Appendix 3.

pycnocline. Depth range in the water column in which density changes rapidly in the vertical dimension. Compare *halocline* and *thermocline*.

radioactive (n. **radioactivity)**. Pertaining to a property of certain elements, or isotopes of an element, whose atomic nuclei are unstable and can spontaneously disintegrate and emit ionizing radiation.

radioisotope. Radioactive isotope of an element that may also have nonradioactive isotopes.

radiolaria (sing. **radiolarian;** adj. **radiolarian)**. Planktonic and benthic protozoa of the phylum Sarcodina that are protected by shells that are usually siliceous. See Appendix 3.

radionuclides. Nuclei of radioactive atoms.

reef. Rocky elevation of the seafloor whose upper part is at depths of less than about 20 m. The term is often restricted to such areas that pose a hazard to navigation.

reef flat. Platform of coral fragments and sand that is relatively exposed at low tide. Also called "reef terrace."

reef terrace. See *reef flat*.

refraction (v. **refract;** adj. **refracted)**. Process by which part of a wave is slowed, causing the wave to bend as it passes from one zone to another in which it travels at a different speed. Refraction occurs as a water wave enters shallow water, or as a sound wave or light wave crosses an interface between two fluids or crosses a thermocline or halocline.

relict sediment. Sediment that was deposited under a set of environmental conditions that have since changed, but has not been buried by more recent sediment.

reptiles. Species of the class Reptilia, subphylum Vertebrata, phylum Chordata. Reptiles breathe air and are cold-blooded. The few marine species include turtles and sea snakes. See Appendix 3.

residence time. Average length of time that a particle of any substance spends in a defined part of the ocean. See **CC8**.

residual current. Current that remains after the reversing tidal current components have been subtracted. Residual current is indicative of the mean drift after multiple tidal cycles.

respiration (v. **respire)**. Process by which organisms use organic materials (food) as a source of energy. Respiration normally uses oxygen and produces carbon dioxide.

restoring force. Force that tends to restore a disturbed ocean surface to a flat configuration.

resuspend (adj. **resuspended)**. To lift particles off the sediment surface (by currents) or the ground (by winds) on which they have been temporarily deposited. Particles become suspended sediment and airborne dust in water and air, respectively.

rift zone. Zone where the Earth's crust is being torn apart. Rift zones are often elongated and may be locations where tectonic plates are separating.

rip current. Fast, narrow surface or near-surface current that flows seaward through the breaker zone at nearly right angles to the shore. Rip currents are the seaward return flow of the water piled up on the shore by incoming waves.

rocky intertidal zone. Zone of a rocky coastline between the high- and low-tide lines.

runoff. Freshwater that is returned to the ocean or to a river after falling on the land as rain or snow.

salinity. Measure of the quantity of dissolved salts in ocean water. Salinity is defined in terms of the conductivity of the water relative to the conductivity of a defined salt solution. Salinity has no units but is approximately equal to the weight in grams of dissolved salts per kilogram of seawater.

salps. Members of a genus of pelagic tunicates (subphylum Vertebrata) that are cylindrical and transparent. See Appendix 3.

salt marsh. Relatively flat area of the shore where fine sediment is deposited and salt-tolerant grasses grow.

salt wedge estuary. Estuary, normally deep, that has a large volume of freshwater flow separated by a sharp halocline from a lower wedge-shaped layer of seawater that moves landward. Compare *partially mixed estuary* and *well-mixed estuary*.

sand dune. Rounded mound or hill of sand on the back-shore formed by accumulations of windblown sand. Sand dunes may have rooted vegetation.

saturation pressure. Maximum amount of water that can remain in the vapor phase in air at a particular pressure and temperature expressed as a partial pressure of water vapor (the pressure if only the water vapor were present).

saturation solubility. Concentration of a dissolved substance when no more of the substance can be dissolved in the solvent.

scarp. Linear, steep or nearly vertical topographic feature that separates areas of gently sloping or flat surfaces. Compare *berm*.

scatter (adj. **scattered)**. Reflection of light or sound in random directions, generally by particles suspended in a fluid. Compare *backscatter*.

scavengers (v. **scavenge)**. Animals that feed on dead organisms.
school (adj. **schooling)**. Aggregation of fishes, squid, or crustaceans that is organized to remain together as the organisms move.
scuba. Abbreviation for "self-contained underwater breathing apparatus," the means by which humans descend beneath the sea surface carrying their own source of air to breathe.
sea cucumbers. Members of the class Holothuroidea, phylum Echinodermata. See Appendix 3.
sea fans. Corals whose colonies grow out from a point of attachment to the substrate in a form resembling an intricate fan. Sea fans belong to the order Alcyonacea. See Appendix 3.
sea grasses. Any of several species of rooted plants of the class Angiosperma that grow predominantly in marshes and shallow-water lagoons. See Appendix 3.
sea stars. Animals of the class Anthozoa, phylum Cnidaria, that have a number of radial arms, on the underside of which are numerous tube feet to provide locomotion. The mouth is on the underside at the center. Many sea stars prey on mollusks. See Appendix 3.
sea urchins. Animals belonging to the class Echinoidea, phylum Echinodermata. Sea urchins have a fused test (external calcified covering) and well-developed spines. See Appendix 3.
seafloor spreading. Process producing oceanic crust by upwelling of magma along the axis of the oceanic ridges.
seamount. Individual peak of seafloor topography that rises more than 1000 m above the ocean floor.
seawall. Wall built parallel to the shore to protect the shore from erosion by waves.
sediment. Particles of organic or inorganic origin that accumulate in loose form.
sedimentary arc. Chain of low sedimentary islands formed at some oceanic convergent plate boundaries between the boundary and the magmatic arc.
sedimentation. Accumulation of particles on the seafloor by progressive deposition of particles from the suspended sediment to form sediments.
sedimentation rate. Rate of accumulation of sediments, normally measured in millimeters of sediment thickness per thousand years in the open ocean.
seismograph. Instrument that detects and records earthquake waves that have traveled through the Earth from an earthquake focus.
semidiurnal tide. Tide with two high and two low tides each tidal day, with the two highs and the two lows being equal or almost equal to each other in height. Compare *diurnal tide* and *mixed tide*.
sensible heat. Heat that, when added to or removed from a substance, changes the temperature of that substance.
sewage sludge. Solids or slurry remaining after sewage wastewater has been treated. Sewage sludge contains pathogens, trace metals, nutrients, and other contaminants.
shallow-water wave. Wave whose wavelength is at least 20 times the depth of water beneath it. Compare *deepwater wave* and *intermediate wave*.
shear stress. Resistance (friction) that develops at the interface between two fluids that are moving in relation to each other.
shelf break. Depth at which the gradual seaward slope of the continental shelf steepens appreciably, defining the boundary between the continental shelf and the continental rise.
shelf valley. Valley in the seafloor topography that cuts across the continental shelf. Shelf valleys are usually "drowned river valleys."
shellfish. Animals of the phylum Crustacea or Mollusca that have hard outer shells. The term generally is applied to species that are valuable for human consumption.
shoal. Shallow place in a body of water that presents a hazard to navigation. Shoals are often in the form of a sandbank or sandbar whose surface may be exposed when the tide is low.
shore. Zone between the highest level of wave action during storms and the lowest low-tide line.
shoreline. Line that marks the intersection of the water surface with the shore. The shoreline migrates up and down as the tide rises and falls. Compare *coastline*.
siliceous. Pertaining to material containing abundant silica.
sill. Submarine ridge that separates the deeper parts of two adjacent ocean basins. Sills are often present at the mouths of fjords and other coastal embayments or at the entrances to marginal seas.
slack water. The time when the current speed is zero as a reversing tidal current changes direction.
slump. Collapse of a mass of earth or sediments from the sides of sloping topography, and movement of this mass downward on the slope.
soft corals. Species of corals that do not secrete massive calcareous skeletons and do not have zooxanthellae.
solar wind. A stream of charged subatomic particles (mainly protons and electrons) that flows outward from the sun and other stars.
solstice. Time of year when the sun is directly over one of the tropics. Solstices occur on June 20 or 21 when the sun is over the Tropic of Cancer in the Northern Hemisphere and on December 21 or 22 when the sun is over the Tropic of Capricorn in the Southern Hemisphere. Compare *equinox*.
solubility (adj. **soluble)**. Ability of a substance to be dissolved in a liquid. The term is generally used to mean saturation solubility.
sonar. Abbreviation of "sound navigation and ranging," a method by which sound pulses can be used to measure the distance to objects in the ocean.
sorted. Describing the range of grain sizes in a sediment. Well-sorted sediment consists of grains that have a restricted range of grain sizes.
sounding. Measuring the depth of water beneath a ship.
spatial. Pertaining to the location of points in three-dimensional space. The term is used in the same way that *temporal* is used with respect to points in time.
spawn. To produce eggs, which may be laid in one location or dispersed in the water.
species. Population of organisms whose members interbreed under natural conditions and produce fertile offspring and that is reproductively isolated from other such groups. See Appendix 3.
species succession. Sequence of dominance by different species of phytoplankton during seasonal changes, especially in mid-latitude marine ecosystems.
spit. Narrow strip of land, commonly consisting of sand deposited by longshore currents, that has one end attached to the mainland and the other terminating in open water.
sponges. Animals of the phylum Porifera, most of which are

microscopic but build massive colonies. Sponges are filter feeders. See Appendix 3.

spore. Small reproductive body that is highly resistant to decomposition but is capable of growing and metamorphosing to produce an adult form either immediately or after a prolonged interval of dormancy.

spreading cycle. Period during which the continental crust on the Earth's surface is broken into a number of pieces that move apart on their lithospheric plates. Spreading cycles are preceded and followed by a period when the continents are brought together.

spring tide. Tide that has the greatest range within a lunar month. Spring tides occur twice during the month, when the moon is new and when it is full. Compare *neap tide*.

standing stock. Biomass of a population present at any given time.

standing wave. Waveform that oscillates vertically without progressive movement. Compare *progressive wave*.

steady state. Condition of equilibrium in a system in which the inputs of a substance or energy are equal to the outputs and the distribution of the substance or energy within the system does not change with time.

storm surge. Temporary rise of sea level above its normal height as a result of wind stress and reduced atmospheric pressure during storms.

stratification (adj. **stratified)**. Layering of fluids according to density. Stratification is stable when density decreases continuously (but not necessarily uniformly) with distance from the Earth's center.

subduction (adj. **subducted)**. Process by which one lithospheric plate descends beneath another.

subduction zone. Area in which a lithospheric plate is descending into the asthenosphere.

sublittoral zone. Benthic environment extending from the low-tide line to a depth of 200 m.

submarine canyon. Steep, *V*-shaped canyon cut into the continental shelf or slope.

submersible. Undersea vehicle with an enclosure that has an atmosphere in which human passengers can be transported.

subtropical gyre. Circular current system centered in the subtropical high-pressure region of each major ocean basin, driven by the trade winds and westerly winds. The subtropical gyres rotate clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere.

subtropical high. one of several regions of semipermanent high atmospheric pressure located over the oceans between 20° and 40° of latitude in both the Northern and Southern hemispheres of the Earth—associated with the downwelling zone of the Hadley cells

supernova (pl. **supernovae)**. Violent explosion of a star that is many times more massive than our sun. The exploding star may become temporarily extremely bright. Matter is thrown off into space at high velocity and high energy during the explosion, and the star collapses to become either a neutron star or a black hole.

superplume. Massive upwelling of warmer mantle material that arises from extended areas near the Earth's core. There are thought to be two such superplumes on the present-day Earth. They may each feed numerous hot spots.

supersaturated. Describing an unstable condition in which the concentration of a dissolved substance (or of water vapor in air) is greater than the saturation solubility. The substance (or water vapor) may not precipitate unless provided with nuclei (such as suspended particles or dust) on which to deposit.

supralittoral zone. Splash or spray zone above the spring high-tide shoreline.

surf. Turbulent foam produced by breaking waves. The term is also used to mean "surf zone."

surf zone. Region between the shoreline and offshore in which most wave energy is released by breaking waves.

surface microlayer. Thin (about 0.1 mm thick) layer that covers the entire ocean surface and has different properties than the underlying water has. Often called a "slick."

surface tension. Tendency for the surface of a liquid to contract because of the attractive forces between its molecules.

survival niche. Range of environmental variables within which the individuals of a species can survive. Compare *fundamental niche*.

suspended sediment. Small solid particles that sink slowly or are maintained in suspension and distributed in the water column by turbulence.

suspension feeders (adj. **suspension-feeding)**. Animals that feed by capturing or filtering suspended particles from the water column. Compare *filter feeders*.

swash. Water that washes up over exposed beach as waves break at the shore.

swell. Smoothly undulating ocean wave that is the result of wave dispersion and that is transported with little energy loss across great stretches of ocean.

swim bladder. Gas-containing flexible organ in many fish species that aids in attaining neutral buoyancy.

symbiosis (adj. **symbiotic)**. Association between two species in which one or both benefit. A species in such an association that does not benefit may be harmed or may be unaffected by the association.

synoptic. Describing measurements made simultaneously at many different locations.

tectonic estuary. Estuary whose origin is related to tectonic deformation of the coastal region.

teratogens (adj. **teratogenic)**. Chemicals that cause mutations in the offspring of organisms that are exposed to them. Compare *carcinogens* and *mutagens*.

terrigenous. Pertaining to material derived from the land.

territorial sea. Strip of ocean 12 nautical miles wide adjacent to land within which the coastal nation has control over the passage of ships.

thermocline. Depth range in the water column in which temperature changes rapidly in the vertical dimension. Compare *halocline* and *pycnocline*.

thermohaline circulation. Vertical movements of ocean water masses caused by density differences that are due to variations in temperature and salinity.

tidal range. Height difference between high and low tides. The term can apply to the tides of a single day or to the highest high and lowest low of a specified period, such as a month.

tide. Periodic rise and fall of the ocean surface caused by differences in the gravitational attraction due to the moon and sun on different parts of the Earth.

tide pool. Depression in the intertidal zone that remains wet or filled with water when the tide recedes below its level on the

shore.

tomography (adj. **tomographic)**. Method of mapping the internal parts of the Earth, ocean, or other body by observing waves transmitted through the body as they arrive at various points on its surface. The resulting data are used to produce a three-dimensional view of the internal variations of wave transmission velocity.

topography (adj. **topographic)**. Shapes, patterns, and physical configuration of the surface of the land or seafloor, including its relief (local differences in elevation or depth) and the positions of natural and human-made features.

tracer. Chemical constituent that has variable concentrations in seawater that can be used to identify and follow the movement of water masses.

trade wind. Air mass that moves from subtropical high pressure belts toward the equator. Trade winds are northeasterly in the Northern Hemisphere and southeasterly in the Southern Hemisphere. Compare *westerly*.

transform fault. Fault that offsets the boundary between the edges of two lithospheric plates.

transform plate boundary. Boundary between two tectonic plates where the motion is such that two plate edges are sliding past each other.

trench. Long, narrow, and deep depression on the ocean floor that has relatively steep sides.

trophic efficiency. See *food chain efficiency*.

trophic level. With primary producers as the first level, the number of steps in a food chain to a particular organism. Organisms that eat primary producers are at the second level, organisms that eat second-level organisms are at the third level, and so on.

troposphere. Zone of the atmosphere between the Earth's surface and an altitude of about 12 km.

trough. The part of an ocean wave that is displaced below the still-water line. Compare *crest*.

tsunami. Long-period gravity wave generated by a submarine earthquake or volcanic event.

tube worms. Many species of worms that live within a rigid tube that they secrete, drill into the substrate, or construct with shell fragments and sand. Tube worms are usually filter feeders that extend feeding tentacles from the tube into the water column to capture suspended particles.

tuned. Pertaining to a wave oscillation whose wavelength is such that successive wave crests enter a basin or enclosure at the same time that the crest of a preceding wave returns.

tunicates. Any of various species of the subphylum Urochordata, phylum Chordata. Tunicates include both benthic (sea squirts) and pelagic (salps) species. See Appendix 3.

turbidite. Sediment deposit formed by turbidity currents. Turbidites have vertically graded bedding.

turbidity (adj. **turbid)**. Reduction of the clarity of a fluid caused by the presence of suspended matter.

turbidity current. Episodic fast current that resuspends sediments and carries them down a submarine slope. Turbidity currents may be initiated by a sudden force such as an earthquake.

turbulence (adj. **turbulent)**. Flow of a fluid in which random velocity fluctuations distort and confuse the flow lines of individual molecules.

upwelling (adj. **upwelled)**. Vertical upward movement of a fluid due to density differences; or where two fluid masses converge, displacing fluid upward; or where an upper layer diverges, causing fluid from below to rise into the divergence. In the ocean, the term refers to coastal upwelling, where Ekman transport causes surface waters to move away from the coast and deeper (often cold and nutrient-rich) water to be brought to the surface; or to upwelling caused by winds that move surface water masses away from each other, creating a divergence. Compare *downwelling*.

van der Waals force. Weak force between atoms or molecules caused by the slight polarities of atoms and molecules that are the result of small variations in the configurations of the electron clouds surrounding the atom or molecule.

vertebrates. Animals of the subphylum Vertebrata, phylum Chordata. Vertebrates include species that have a well-developed brain and a skeleton of bone or cartilage.

Examples are fishes, amphibians, reptiles, birds, and mammals (including human beings). See Appendix 3.

virus (adj. **viral)**. Infective agent that can cause disease and can multiply when associated with living cells. Viruses are complex proteins that are not regarded as living organisms.

viscosity (adj. **viscous)**. Property of a substance that causes it to offer resistance to flow. Internal friction.

viviparous. Pertaining to animals that give birth to living young. Compare *oviparous* and *ovoviviparous*.

water mass. Body of water identifiable and distinguishable from other water bodies by its characteristic temperature, salinity, or chemical content.

wave dispersion. Separation of ocean waves by wavelength as they travel away from their point of origin. Longer waves travel faster.

wave height. Vertical distance between a crest and the preceding trough.

wave interference. Combination of two or more simple waves of different periods or traveling in different directions to produce complex waveforms.

wave period. Time that elapses between the passage of two successive wave crests past a fixed point.

wave ray. Path across the sea surface that is followed by a point on a wave front as the wave travels and is refracted and reflected.

wave speed. Speed at which the waveform of a progressive wave travels.

wave steepness. Ratio of wave height to wavelength.

wavelength. Horizontal distance between corresponding points on successive waves, such as from crest to crest.

weather. Temperature, humidity, cloud cover, wind velocity, and other atmospheric conditions, and their variations at a specific location on a given day.

weathering (adj. **weathered)**. Process by which rocks are broken down by chemical and mechanical (winds, ice formation, etc.) means.

well-mixed estuary. Estuary in which vertical mixing by tides or wind is such that there is no vertical stratification. Salinity in well-mixed estuaries increases progressively toward the ocean. Compare *partially mixed estuary* and *salt wedge estuary*.

westerly. Air mass that moves away from a subtropical high-pressure belt toward higher latitudes. Westerlies blow from the southwest in the North Hemisphere and from the north-

west in the Southern Hemisphere. Compare *trade wind*.

western boundary current. Poleward-flowing warm surface layer current that flows on the western side of subtropical gyres. Western boundary currents are fast, narrow, and deep. Compare *eastern boundary current*.

wetlands. Low-lying flat areas that are covered by water or have water-saturated soils for at least part of the year.

windward. The direction from which the wind is blowing. The term usually applies to the exposed side of a landmass or barrier facing the oncoming wind. Compare *leeward*.

zooplankton. Animal plankton. Compare *phytoplankton*.

zooxanthellae (sing. **zooxanthella)**. Forms of algae that live symbiotically in the tissue of corals and other animals and provide some of the host animal's food supply by photosynthesis.

Appendix 1

Units and Conversion Factors

Wherever possible, this text uses metric units of measurement. The metric system of measurement is used by all major countries but the United States, and it is the universal system used by all scientists. At present, an additional process is under way directed toward using only those metric units that are standard units approved in the International System of units (SI units). However, some of these standard units are unfamiliar even to many scientists, so they are not yet universally used. SI units are used in this text if they are generally in wide usage. In some instances where nonstandard units are much more widely used in the United States, the nonstandard units are used in this text. Over time, there will likely be a migration to the universal and exclusive use of SI units. The SI unit system has only seven base units from which all other units are derived (derived units are combinations of the base units). Tables listing the base units of the SI system, some derived SI units, and all of the units used in this text are included in this appendix. Some conversion factors to relate the SI units and other metric units to other units commonly used in the United States are also included.

SI Base Units

	Base Unit	
Base Quantity	**Name**	**Symbol**
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electrical current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole[a]	mol
Luminous intensity	candela	cd

[a] 1 mole is equal to the molecular weight in grams.

The scientific community almost universally uses exponential notation for numbers. Exponential notation is explained in Chapter 1 and is used throughout this text. This appendix includes a table ("Exponential Notation and the Decimal System") for converting exponential numbers to their nonexponential equivalents. To multiply numbers expressed exponentially, add the exponents (superscript numbers). For example, $10^{-1} \times 10^{3} = 10^{2}$ (one-tenth of 1000 is equal to 100). To divide, subtract the exponents. The "SI Base Units" table also lists the common terms used to identify certain exponent values. For example, 1000 is equivalent to 10^{3}, or 1×10^{3}, and 1000 can be expressed as "one thousand," while other units can be prefixed by "kilo-" to express one thousand of the units; for example, 1 kilogram is equal to 1000 grams.

Note that the naming system for large and small numbers is different in different parts of the world. In many non-English-speaking countries (and formerly in England), the term billion does not mean 109. Instead, in this alternate system billion is 10^{12} and trillion is 10^{18}. This is one reason why it is always better to use exponential notation for large or small numbers.

Some Examples of Derived SI Units

Derived Quantity	Name	Symbol
Area	square meter	m^2
Volume	cubic meter	m^3
Speed, velocity	meter per second	$m \cdot s^{-1}$
Acceleration	meter per second squared	$m \cdot s^{-2}$
Mass density	kilogram per cubic meter	$kg \cdot m^{-3}$
Specific volume	cubic meter per kilogram	$m^3 \cdot kg^{-1}$
Current density	ampere per square meter	$A \cdot m^{-2}$
Magnetic field strength	ampere per meter	$A \cdot m^{-1}$
Amount-of-substance concentration	mole per cubic meter	$mol \cdot m^{-3}$
Luminance	candela per square meter	$cd \cdot m^{-2}$
Mass fraction	kilogram per kilogram, which may be represented by the number 1	$kg \cdot kg^{-1} = 1$

SI Derived Units with Special Names and Symbols[a]

	SI Derived Unit			
Derived Quantity	**Name**	**Symbol**	**Expression in Terms of Other SI Units**	**Expression in Terms of SI Base Units**
Plane angle	radian	rad	—	$m \cdot m^{-1} = 1$
Frequency	hertz	Hz	—	s^{-1}
Force	newton	N	—	$m \cdot kg \cdot s^{-2}$
Pressure, stress	pascal	Pa	$N \cdot m^{-2}$	$m^{-1} \cdot kg \cdot s^{-2}$
Energy, work, quantity of heat	joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
Power, radiant flux	watt	W	$J \cdot s$	$m^2 \cdot kg \cdot s^{-3}$
Celsius temperature	degree Celsius	°C	—	K
Luminous flux	lumen	lm	$cd \cdot sr$	$m^2 \cdot m^{-2} \cdot cd = cd$
Illuminance	lux	lx	$lm \cdot m^2$	$m^2 \cdot m^{-4} \cdot cd = m^{-2} \cdot cd$
Activity (of a radionuclide)	becquerel	Bq	—	s^{-1}

[a] For ease of understanding and convenience, a few SI derived units have been given special names and symbols. These are some that are relevant to this text.

Exponential Notation and the Decimal System

Value	Exponential Expression	Name	Prefix
1,000,000,000,000	10^{12}	1 trillion	tera-
1,000,000,000	10^{9}	1 billion	giga-
1,000,000	10^{6}	1 million	mega-
1,000	10^{3}	1 thousand	kilo-
100	10^{2}	1 hundred	centa-
10	10^{1}	ten	deca-
1	10^{0}	one	uni-
0.1	10^{-1}	1 tenth	deci-
0.01	10^{-2}	1 hundredth	centi-
0.001	10^{-3}	1 thousandth	milli-
0.000,001	10^{-6}	1 millionth	micro-
0.000,000,001	10^{-9}	1 billionth	nano-
0.000,000,000,001	10^{-12}	1 trillionth	pico-

Conversions between Basic Units of Length, Mass, and Time

Length:	1 kilometer = 1000 meters (m) 1 meter = 100 centimeters (cm) 1 centimeter = 10 millimeters (mm) 1 millimeter = 10 micrometers (mm) 1 micrometer = 10 nanometers (nm)
Mass:	1 tonne (metric ton) = 1000 kilograms (kg) 1 kilogram = 1000 grams (g) 1 gram = 10 milligrams (mg) 1 milligram = 10 micrograms (mg) 1 microgram = 10 nanograms (ng) 1 nanogram = 10 picograms (pg)
Time:	1 hour = 3600 seconds (s)

Units of Measurement Used in This Text (with Abbreviations)	
Length/distance:	**meter (m) — *SI base unit*** millimeter (mm) centimeter (cm) kilometer (km) foot (ft) — *obsolete nonmetric unit* nautical mile (n.m.) — *equals 1.853 km (1.15 statute miles) or 1 minute (1/60 of a degree) of longitude*
Mass:	**kilogram (kg) — *SI base unit*** gram (g) milligram (mg) microgram (μg) tonne (t) — *metric ton, equal to 103 kg*
Time:	**second (s) — *SI base unit*** year (yr) day (day) hour (h) minute (min)
Area:	meter squared (m^2) — *derived SI unit* centimeter squared (cm^2) kilometer squared (km^2)
Volume:	meter cubed, cubic meters (m^3) — *derived SI unit* centimeter cubed (cm^3) kilometer cubed (km^3) liter (l) — *equals 10 cm^3, so 1 m^3 = 1000* l
Pressure:	pascal (Pa) — *derived SI unit (not used in this text)* kilogram per centimeter squared ($kg \cdot cm^{-2}$) — *equals 9.56 × 10^6 Pa* atmosphere (atm) — *equals 1.03 $kg \cdot cm^{-2}$*
Mass density (absolute density):	kilogram per cubic meter ($kg \cdot m^{-3}$) — *derived SI unit* gram per cubic centimeter ($g \cdot cm^{-3}$)
Speed/velocity:	meters per second ($m \cdot s^{-1}$) — *derived SI unit* centimeters per second ($cm \cdot s^{-1}$) kilometers per hour ($km \cdot h^{-1}$) — *1 $km \cdot h^{-1}$ = 0.28 $m \cdot s^{-1}$ = 28 $cm \cdot s^{-1}$* kilometers per day ($km \cdot day^{-1}$)
Acceleration:	meters per second per second ($m \cdot s^{-2}$)
Temperature:	degrees Celsius (°C)
Energy and related units:	joule (J) — *derived SI unit* joule per meter squared ($J \cdot m^{-2}$) — *used as measure of wave energy* joule per gram ($J \cdot g^{-1}$) — *used as measure of latent heat* joule per gram per degree Celsius ($J \cdot g^{-1} \cdot °C^{-1}$) — *used as measure of heat capacity* calorie (cal) — *obsolete measure of energy* calories per gram ($cal \cdot g^{-1}$) — *obsolete, used as measure of latent heat* calories per gram per degree Celsius ($cal \cdot g^{-1} \cdot °C^{-1}$) — *obsolete, used as measure of heat capacity*
Concentration:	mole per cubic meter ($mol \cdot m^3$) — *derived SI unit (not used in this text)* milligram per kilogram ($mg \cdot kg^{-1}$) microgram per kilogram ($\mu g \cdot kg^{-1}$) Notes: *Concentrations are expressed as mass of dissolved (or constituent) substance in one unit mass of the solution (or combined mixture).* *1 mole is defined as the molecular weight of a substance expressed in grams. To convert concentration in $mg \cdot kg^{-1}$ to $mol \cdot m^{-3}$, divide by the molecular weight of the dissolved substance (or constituent); then divide by the solution (or mixture) density in $kg \cdot m^3$ and multiply by 1000.*
Miscellaneous:	grams per year ($g \cdot yr^{-1}$) — *mass transport rate* cubic meters per second ($m^3 \cdot s^{-1}$) — *volume transport rate* practical salinity unit — *dimensionless ratio; no abbreviation, but sometimes listed as PSU* millions of years ago (MYA) — *millions of years before the present date* before the common era (BCE) — *number of years before the year 1 of the Christian calendar, equivalent to BC* the common era (CE) — *number of years after the year 1 of the Christian calendar, equivalent to AD*

Additional Conversions

Metric to Other Unit Conversions	Other Unit to Metric Conversions
LENGTH	
1 km = 0.62 statute miles	1 statute mile = 1.609 km
1 km = 0.54 nautical miles	1 nautical mile = 1.852 km
1 km = 1093 yards	1 yard = 39.4 inches
1 m = 39.4 inches	1 foot = 30.5 cm
1 m = 3.28 feet	1 inch = 2.54 cm
1 cm = 0.394 inches	
MASS	
1 kg = 2.2 pounds	1 pound = 0.45 kg
1 tonne (metric ton) = 2205 pounds	1 pound = 450 g
1 tonne (metric ton) = 1.10 U.S. tons	1 U.S. ton = 907 kg
1 g = 0.035 ounce	1 ounce = 28.4 g
AREA	
$1\ km^2$ = 0.386 statute mile squared	1 statute mile squared = $2.59\ km^2$
$1\ km^2$ = 247.1 acres	1 acre = $4050\ m^2$
$1\ m^2$ = 10.7 feet squared	1 foot squared = $929\ cm^2$
$1\ cm^2$ = 0.155 inch squared	1 inch squared = $6.45\ cm^2$
VOLUME	
$1\ m^3$ = 35.3 feet cubed	1 foot cubed = 28.32 l (0.028 m^3)
$1\ m^3$ = 264 U.S. gallons	1 U.S. gallon = 3.78 l (0.0037 m^3)
$1\ cm^3$ = 0.061 inch cubed	1 inch cubed = $16.4\ cm^3$
1 l = 2.12 pints	1 pint = 0.47 l
PRESSURE	
$1\ kg \cdot cm^{-2}$ = 14.2 pounds per inch squared	1 atmosphere (sea level) = $1.03\ kg \cdot cm^{-2}$
$1\ kg \cdot cm^{-2}$ = 0.97 atmosphere	1 bar = $1.04\ kg \cdot cm^{-2}$
$1\ kg \cdot cm^{-2}$ = 956 millibars	1 pascal = $0.000{,}001\ kg \cdot cm^{-2}$
$1\ kg \cdot cm^{-2}$ = 0.956 bar	1 inch of mercury at 0°C = $0.034\ kg \cdot cm^{-2}$
$1\ kg \cdot cm^{-2}$ = 956,000 pascals	1 mm of mercury at 0°C = $0.0013\ kg \cdot cm^{-2}$
$1\ kg \cdot cm^{-2}$ = 29.0 inches of mercury at 0°C	
$1\ kg \cdot cm^{-2}$ = 737 mm of mercury at 0°C	
SPEED	
$1\ km \cdot h^{-1}$ = 0.62 mile per hour	1 mile per hour = $1.61\ km \cdot h^{-1}$
$1\ km \cdot h^{-1}$ = 0.54 knot	1 knot = $1.85\ km \cdot h^{-1}$
$1\ cm \cdot s^{-1}$ = 1.97 feet per minute	1 foot per minute = $0.51\ cm \cdot s^{-1}$
$1\ cm \cdot s^{-1}$ = 0.033 foot per second	1 foot per second = $30.5\ cm \cdot s^{-1}$
TEMPERATURE	
0°C = 32°F	–40°F = –40°C
10°C = 50°F	0°F = –17.8°C
20°C = 68°F	32°F = 0°C
30°C = 86°F	40°F = 4.4°C
40°C = 104°F	50°F = 10°C
100°C = 212°F	70°F = 21.1°C
	90°F = 32.2°C
	100°F = 37.8°C
	212°F = 100°C

Appendix 2

Dimensions of the Earth and Oceans

The Earth	
Radius at equator	6,378 km
Radius at poles	6,357 km
Average radius	6,371 km
Circumference at equator	40,077 km

Areas of Land and Oceans	
Land (29.22% of total)	149,000,000 km^2
Oceans and seas (70.78%)	361,000,000 km^2
Pacific Ocean (marginal seas included)	180,000,000 km^2
Atlantic Ocean (marginal seas included)	107,000,000 km^2
Indian Ocean (marginal seas included)	74,000,000 km^2
Ice sheets and glaciers	15,600,000 km^2
Land plus continental shelf	177,400,000 km^2
Land in the Northern Hemisphere	100,200,000 km^2
Ocean in the Northern Hemisphere	154,800,000 km^2
Land in the Southern Hemisphere	48,700,000 km^2
Ocean in the Southern Hemisphere	206,300,000 km^2

Percentage of Ocean Area Occupied by Ocean Provinces	
Continental shelf and slope	15.3%
Continental rise	5.3%
Abyssal seafloor	41.8%
Volcanoes and volcanic ridges	3.1%
Oceanic ridges and rises	32.7%
Trenches	1.7%

Density and Mass of the Earth's Parts			
	Average Thickness or Radius (km)	**Mean Density ($g \cdot cm^{-1}$)**	**Total Mass ($\times 10^{24}$ g)**
Atmosphere	—	—	0.005
Oceans and seas	3.8	1.03	1.41
Ice sheets and glaciers	1.6	0.90	0.023
Continental crust (includes continental shelves)	35	2.8	17.39
Oceanic crust (excludes continental shelves)	8	2.9	7.71
Mantle	2881	4.53	4068
Core	3473	10.7	1881

Elevations and Depths	
Average elevation of land	840 m
Average depth of oceans	3,800 m
Average depth of Pacific Ocean (marginal seas excluded)	3,940 m
Average depth of Atlantic Ocean (marginal seas excluded)	3,310 m
Average depth of Indian Ocean (marginal seas excluded)	3,840 m
Highest elevation of land (Mount Everest)	8,848 m
Greatest depth of oceans (Mariana Trench)	11,035 m

Appendix 3

Classification of Marine Organisms

Understanding life on the Earth and how this life has evolved and may evolve in the future in response to human influences requires that we understand the differences between the many forms of life on the Earth, and how and why the differences have developed. Fundamental to such studies is taxonomy, the classification of organisms to express their relationship to each other.

One fundamental concept of taxonomy is that organisms can be identified as belonging to a species. The definition of a species is generally accepted to be a population of organisms whose members interbreed under natural conditions and produce fertile offspring that are reproductively isolated from other such groups. A new definition based on genetics, the composition of DNA, may be developed in the future. The current definition has generally worked well, although there are difficulties, for example, when two populations that are capable of interbreeding are geographically separated and do not interbreed. In some such cases, scientists disagree as to whether these separate populations are of the same species or are different enough to be considered separate species. Populations of king salmon that breed in different rivers along the coasts of the United States and Canada are an example. Other difficulties arise because the members of a single species may look very different. For example, bulldogs, terriers, and poodles all belong to the same species. Conversely, organisms that appear to be very similar may belong to different species; red squirrels and gray squirrels are an example.

Millions of species on the Earth have been identified and studied, and certainly many more millions remain to be found, particularly in tropical rain forests and coral reefs. Species are arranged in a hierarchical classification similar to a human family tree. Taxonomists have established a series of levels for this hierarchy, from species at the bottom to kingdom, which was the top level until recent years, when a new top level—domain—was added. This new top level became needed when archaea were discovered. Initially placed in a kingdom along with bacteria, archaea were subsequently found to be entirely different from bacteria. In fact, archaea are different enough that they do not fit into any of the five kingdoms that were previously recognized and that are still listed in many texts. Although the new top level (domain) is not yet universally accepted, the generally accepted classification now identifies three such domains:

Three Domains of Living Organisms	
Domain I: Bacteria – Most of the Known Prokaryotes Although it is clear that the bacteria need to be separated into kingdoms, they are not well enough studied for this to have been done yet. At present they are separated into five phyla.	
Phylum Proteobacteria	Nitrogen-fixing bacteria
Phylum Cyanobacteria	Photosynthetic bacteria (formerly blue-green algae)
Phylum Eubacteria	True gram-positive bacteria
Phylum Spirochetes	Spiral bacteria
Phylum Chlamydiae	Intracellular parasites
Domain II: Archaea – Prokaryotes of Extreme Environments	
Kingdom Crenarchaeota	Thermophiles
Kingdom Euryarchaeota	Methanogens and halophiles
Kingdom Korarchaeota	Some hot-springs microbes
Domain III: Eukarya – Eukaryotic Cells	
Kingdom Protista	Single-celled organisms that have a nucleus and other internal structure in the cell (e.g., diatoms)
Kingdom Fungi	Multicelled organisms that are not able to photosynthesize (or chemosynthesize)
Kingdom Plantae (or Metaphyta)	Multicelled photosynthetic autotrophs (e.g., kelp)
Kingdom Animalia (or Metazoa)	Multicelled heterotrophs (invertebrates and vertebrates)

Viruses have traditionally been considered to be non-living (since they cannot reproduce without a host). However, this view is now changing and viruses may soon be recognized as life. In addition, there is now evidence that viruses may have preceded all of the other existing kingdoms, that they stand somewhere at the base of the tree of life and may have evolved into cellular organisms. As a result, it is likely that viruses will have to be found a place within the texonomic hierarchy. Whether this will require reorganization of the 3 Domain stucture show in the table above to include a new Domain, a new Kingdom or lower order, or even a new classification level above Domain is not yet clear.

The taxonomic hierarchy generally has nine levels, although sometimes one or another level is omitted, sometimes intermediate levels are added within the hierarchy, and there is, as yet, no universal agreement on the use of the top level, domains. The major levels in the hierarchy are as follows:

Domain
Kingdom
Phylum
Subphylum
Class
Order
Family
Genus
Species

The principal phyla and classes to which all common marine species belong and some examples of each type are listed at the end of this appendix.

Scientific names of organisms are important for many reasons, one of which is that common names are often confusing. For example, the common name "red snapper" is used in the Gulf of Mexico for the species *Lutjanus campechanus.* In the Pacific Ocean the same common name, "red snapper," is used for at least three different species (*Lutjanus bohar, Lutjanus malabaricus,* and *Lutjanus gibbus*) that are related but very different from one another. This difference does not matter to the local populations who eat these fishes (indeed, when you order red snapper in a restaurant, you may be served any one of many species that may not even be snappers). However, scientists must be able to distinguish them in the literature, and they do so by using scientific names.

The scientific names given to species always consist of two parts: a genus name followed by a species name. For example, mussels are classified as follows:

- Domain: Eukarya
- Kingdom: Animalia (Metazoa)
- Phylum: Mollusca
- Class: Bivalvia
- Order: Mytiloida
- Superfamily: Mytilacea (this is good example of an intermediate level used in the taxonomic hierarchy for only some orders)
- Family: Mytilidae
- Genus: Mytilus

The common blue mussel of the east coast of North America is *Mytilus edulis,* and a different species, *Mytilus californianus,* is present only on the west coast.

These and other scientific names may seem complicated, but they are either Latin or Greek words modified to explain something that the taxonomist considers important in identifying the organism. For example, "*Mytilus*" is derived from the Greek word for sea mussels, "*californianus*" expresses that this species is present only on the West Coast ("c*alifornia"*); and "*edulis*" means "edible," a suitable term for this species that is so good to eat. *Similarly,* the genus name *Sargassum* is applied to species of algae present in the Sargasso Sea, and *Enterococcus* is the genus name for species of bacteria ("*-coccus*") that are present in vertebrate intestines ("*Entero-*").

Scientific names can be complicated and sometimes obscure, but in general, they follow an internationally accepted set of rules. Note that the convention is to use italics for scientific names and to capitalize the genus name only. In addition, shortening the genus name is acceptable where it is clear. For example, this text refers to mussels as *M. edulis* and *M. californianus* after the full names have been used once. There are other conventions as well. For example, "sp." after the genus name refers to a single species of the genus whose species name is not known, and "spp." after the genus name indicates that all (or many) of the species of that genus are being referred to (e.g., "*Mytilus sp."* refers to an unstated or unknown species of mussel, and "*Mytilus spp.*" refers to all or any species of mussel). The *"sp."* and *"spp."* are often omitted, as is done for simplicity in many cases in this text. Sometimes the genus name is followed by abbreviations such as "cf." and "aff." The first of these abbreviations ("cf.") means that the genus listed is thought to be correct and that the species is very similar to the species identified by the name following the genus name and "cf." but there are enough differences to lead the investigator to believe that this may turn out to be a new, but very closely related, species or a subspecies. The second abbreviation ("aff.") means that the species is very similar to the species identified by the name following the genus

name and "aff." but it is sufficiently different that it is most likely an undescribed species similar to the one named.

Taxonomic Classification

Phyla that have no members in the marine environment, as well as phyla in which all species are extinct, are omitted from the following list. The list includes general descriptions of members of each classification and, in some cases, examples of common species and a listing of figures in this text that show a photograph of a member of this classification. The classification presented is not accepted by all taxonomists. Classifications, including the distinctions between phyla, continually change as more is learned.

- **DOMAIN ARCHAEA**. Organisms that have no nucleus, predominantly single-celled. Occur primarily in extreme environments.
  Kingdom Crenarchaeota. Thermophiles.
  Kingdom Euryarchaeota. Methanogens and halophiles.
  Kingdom Korarchaeota. Some hot-springs microbes.
- **DOMAIN BACTERIA.** Organisms that have no nucleus, predominantly single-celled.
  Phylum Proteobacteria. Nitrogen-fixing bacteria.
  Phylum Cyanobacteria. Photosynthetic bacteria (formerly blue-green algae).
  Phylum Eubacteria. True gram-positive bacteria.
  Phylum Spirochetes. Spiral bacteria.
  Phylum Chlamydiae. Intracellular parasites.
- **DOMAIN EUKARYA, KINGDOM PROTISTA.** Organisms with a nucleus confined by a membrane, predominantly single-celled.
  Phylum Chrysophyta. Diatoms (Figs. 8-5, 12-15a), coccolithophores (Figs. 8-6, 12-15c), silicoflagellates (Fig. 12-15d).
  Phylum Pyrrophyta. Autotrophic dinoflagellates (Fig. 12-15b), zooxanthellae.
  Phylum Chlorophyta. Green algae (Fig. 15.3a,d; 15-12f).
  Phylum Phaeophyta. Brown algae. Kelps (Figs. 12-3b; 15.3a,c; 15-7c), *Sargassum* (Figs. 12-3a, 15-13a), and others.
  Phylum Rhodophyta. Red algae (Fig. 15.3a,b,e).
  Phylum Zoomastigophora. Flagellated protozoa, including heterotrophic dinoflagellates.
  Phylum Sarcodina. Amoebas and relatives, including foraminifera (Figs. 8-7a, 12-18c) and radiolaria (Figs. 8-8, 12-18d).
  Phylum Ciliophora. Protozoa with cilia.
- **DOMAIN EUKARYA, KINGDOM FUNGI.** Fungi, lichens.
  Phylum Mycophyta. Marine fungi are primarily benthic decomposers. Marine lichens are primarily intertidal.
- **DOMAIN EUKARYA, KINGDOM PLANTAE (METAPHYTA).** Autotrophic multicelled plants.
  Phylum Tracheophyta. Plants that have roots, stems, and leaves and special cells that transport nutrients and water.
    Class Angiosperma. Flowering plants with seeds contained in a closed seedpod. Turtle grass (*Thalassia;* Fig. 14-11b), marsh grasses (*Spartina;* Fig. 14-11c).
- **DOMAIN EUKARYA, KINGDOM ANIMALIA (METAZOA).** Multicelled heterotrophs (animals).
  Phylum Placozoa. Amoeba-like multicelled animals.
  Phylum Mesozoa. Wormlike parasites of cephalopods.
  Phylum Porifera. Sponges (Fig. 14-27m).
  Phylum Cnidaria (Coelenterata). Jellyfish and related organisms, all of which have stinging cells.
    Class Hydrozoa. Polypoid colonial animals, most with a medusa-like stage. Includes Portuguese man-of-war (Fig. 12-19c).
    Class Scyphozoa. Jellyfish with no (or reduced) polyp stage in life cycle. Medusa stage dominates (Fig. 12-19a,b).
    Class Anthozoa. Zooanthids (Fig. 14-7h), anemones (Figs. 14-5c; 14-7g,i; 14-19a; 14-34a; 15-8b), sea pens (Fig. 14-5a,b), and corals (Figs. 15.11a,b; 14-7a–f; 14-27a; 15-4e,f; 15-6; 15-8a) that have only a polypoid body form.
  Phylum Ctenophora. Comb jellies (Fig. 12-19d), "sea gooseberries." Predatory, predominantly planktonic.
  Phylum Platyhelminthes. Flatworms, flukes, tapeworms. Many are parasitic; many others are free-living predators.
  Phylum Nemertea. Ribbon worms. Benthic and pelagic.
  Phylum Gnathostomulida. Microscopic, wormlike, meiofaunal (small organisms that live in the spaces between sediment grains).
  Phylum Gastrotricha. Microscopic, ciliated, meiofaunal.
  Phylum Rotifera. Ciliated, less than about 2 mm long. Most species freshwater. Planktonic or epibenthic.
  Phylum Kinorhyncha. Small, spiny, segmented worms; meiofaunal.

Phylum Acanthocephala. Spiny-headed worms. All are intestinal parasites of vertebrates.

Phylum Entoprocta. Small polyplike suspension feeders.

Phylum Nematoda. Roundworms. Most are 1 to 3 mm; marine species are infaunal.

Phylum Bryozoa. Small moss animals that form encrusting or branching colonies on seafloor (Fig. 15-13a).

Phylum Phoronida. Suspension-feeding tube worms. Infaunal; inhabit shallow and temperate sediments.

Phylum Brachiopoda. Lamp shells. Bivalve animals that superficially resemble clams. Mostly deep-water.

Phylum Mollusca. Soft-bodied animals with a mantle and muscular foot. Most species secrete a calcium carbonate shell.

- **Class Monoplacophora.** Limpetlike shells, segmented bodies, abyssal only.
- **Class Polyplacophora.** Chitons (Fig. 15-12d). Oval, flattened body covered by eight overlapping plates.
- **Class Aplacophora.** Worm-shaped mollusks; soft-sediment infauna.
- **Class Gastropoda.** Snails (Figs. 14-2b, 14-18b, 14-27h, 15-12a), limpets (Fig. 15-12b), abalones, pteropods (Figs. 8-7b, 14-2a), nudibranchs (Figs. 14-10c,d; 14-27d–g; 15-8f), and many others (Figs. 14-10b, 14-18c, 14-33s).
- **Class Bivalvia.** Clams (Fig. 14-34d), scallops, oysters (Fig. 14-6b), mussels (Figs. 14-6a, 15-12e). Bivalves (shell with two fitted segments). Mostly filter-feeding.
- **Class Scaphopoda.** Tusk shells. Soft-sediment infauna.
- **Class Cephalopoda.** Squid (Fig. 12-23a, 14-27i), octopi (Fig. 14-17e), cuttlefish (Fig. 12-23b–d, 14-27j), *Nautilus* (Fig. 12-23e,f). No external shell except in *Nautilus spp.*

Phylum Priapulida. Small, wormlike, subtidal.

Phylum Sipuncula. Peanut worms, benthic, exclusively marine.

Phylum Echiura. Spoon worms. Spoon-shaped proboscis. Infaunal or live under rocks.

Phylum Annelida. Segmented worms. Mostly benthic. Includes feather duster worms (Fig. 14-5d), scale worms (Fig. 14-33r), and Christmas tree worms (Fig. 14-9c,d).

Phylum Tardigrada. Meiofaunal. Eight-legged. Can hibernate for long periods.

Phylum Pentastoma. Tongue worms. Parasites of vertebrates.

Phylum Pogonophora. Tube-dwelling worms with no digestive system. Absorb food through body wall. All species are marine. Mostly deep-water (Fig 15-17b).

Phylum Echinodermata. Spiny-skinned animals. Most are benthic epifaunal or infaunal.

- **Class Asteroidea.** Sea stars (Figs. 15-4b, 15-8e).
- **Class Ophiuroidea.** Brittle stars, basket stars (Fig. 14-9b).
- **Class Echinoidea.** Sea urchins (Figs. 14-10a, 14-17d, 14-34b, 15-4c, 15-9b), sand dollars (Fig. 15-4d), sea biscuits.
- **Class Holothuroidea.** Sea cucumbers (Figs. 14-9a, 14-27l, 15-4a).
- **Class Crinoidea.** Sea lilies and feather stars (Fig. 14-15a,b; 14-33g).

Phylum Chaetognatha. Arrowworms, stiff-bodied, mostly planktonic.

Phylum Hemichordata. Unsegmented infauna with primitive nerve cord. Acorn worms. All marine.

Phylum Arthropoda. Jointed, legged animals with segmented body covered by an exoskeleton.

- ***Subphylum Crustacea. Copepods*** (Figs. 12-18a, 14-31a), krill (Fig. 14-1a), barnacles (Figs. 12-20b; 14-6c,d; 15-12c), amphipods, shrimp (Figs. 14-1b,c; 14-15a,b,j–l; 14-17a; 14-33h–q; 14-34c,e; 15-8d; 15-13c), lobster, crabs (Figs. 12-20a; 14-15f,g; 14-17c; 14-33a–e; 14-34a,b; 15-8c; 15-12g), euphausiids (Fig. 12-18b, 14-1a), isopods (Fig. 14-31b,c).
- ***Subphylum Chelicerata.*** Horseshoe crabs, sea spiders.
- ***Subphylum Uniramia.*** Insects. Only five species of a single genus are present in the ocean.

Phylum Chordata. Animals with a nerve cord and gills, gill slits, or lungs.

- ***Subphylum Urochordata.*** Tunicates (Fig. 14-8a–d), sea squirts, salps (Fig. 12-19e, 14-3).
- ***Subphylum Cephalochordata.*** Lancelets, Amphioxus. Found in coarse temperate and tropical sediments.
- ***Subphylum Vertebrata.*** Spinal column of vertebrae, internal skeleton, brain.
  - **Class Agnatha.** Jawless fishes. Cartilaginous skeletons. Lampreys, hagfishes.
  - **Class Chondrichthyes.** Cartilaginous skeletons. Rays (Fig. 12-22f,h,i), sharks (Fig. 12-22a–e,g), skates, sawfishes, chimeras.
  - **Class Ostreichthyes.** Bony fishes (Figs. 12-21a–d; 14-12a; 14-13a–e; 14-14; 14-15c–e,h,i; 14-16a–g; 14-17b; 14-18a,d–f; 14-19b–f; 14-20; 14-21a–c; 14-22a–g; 14-23a,c; 14-24a–e; 14-25a–g; 14-26a,b; 14-27b,c,k; 14-31a–c; 14-33f,g; 14-34c; 15-6; 15-8g; 15-13b).
  - **Class Amphibia.** No marine species, but one species (Asian mud frog) is known to tolerate marine water. Frogs, toads,

salamanders.

Class Reptilia. Turtles (Figs. 12-26a,b; 14-11d), sea snakes (Fig. 12-26c,d). One species of iguana (Fig. 12-26e) and one species of crocodile are marine.

Class Aves. Birds (Figs. 12-27, 19.13b). Many species live on and feed in the ocean, but all must return to land to breed.

Class Mammalia. Warm-blooded animals that have mammary glands and hair, bear live young.

Order Cetacea. Whales (Fig. 12-24b,c), porpoises, dolphins.

Order Sirenia. Sea cows. Manatee (Fig. 12-24d), dugong.

Order Carnivora. Marine species in two suborders.

Suborder Pinnipedia. Seals (Figs. 12-25a,b, 15-14a,b,c),sea lions (Fig. 12-25c, 19.13a), walrus (Fig. 12-25d).

Suborder Fissipedia. Sea otters (Figs. 12-25e, 15-9a).

Order Primates. Primates. Apes, human beings. Only one species is known to tolerate marine water—surfers, swimmers, scuba divers.

The phyla Porifera, Cnidaria, Platyhelminthes, Nematoda, Mollusca, Arthropoda, Arthropoda, and Chordata each have more than 10,000 known member species. The phyla Cyanobacteria, Chrysophyta, Pyrrophyta, Chlorophyta, Phaeophyta, Rhodophyta, Zoomastigophora. Sarcodina, Ciliophora, Mycophyta, and Echinodermata each have between approximately 1000 and 10,000 known member species. All other phyla listed have fewer than about 1000 known species. However, it is estimated that there may be between 1 and 10 million species in the oceans, of which only a few hundreds of thousands have yet been identified.

Appendix 4

Some Milestones in the History of Ocean Study

Note: CE = of the common era; BCE = before the common era. These designations are equivalent to the more traditional abbreviations AD (anno Domini) and BC (before Christ), respectively.

ca. 4000 BCE The Egyptians developed shipbuilding and ocean-piloting capabilities.
2000–500 BCE The Polynesians voyaged across the Pacific Ocean and settled all the major islands.
ca. 1100–850 BCE The Phoenicians explored the entire Mediterranean Sea and sailed into the Atlantic to Cornwall, England.
450 BCE The Greek Herodotus compiled a map of the known world centered on the Mediterranean region.
325 BCE The Greek Pytheas explored the coasts of England, Norway, and perhaps Iceland. He developed a means of determining latitude by measuring the angle between the North Star and the horizon, and he proposed a connection between the phases of the moon and the tides.
325 BCE Aristotle published *Meteorologica*, which described the geography of the Greek world, and *Historia Animalium*, the first known treatise on marine biology.
276–192 BCE The Greek Eratosthenes, a scholar at Alexandria, determined the circumference of the Earth with remarkable accuracy, using trigonometry and measurements of the angle of the sun's rays at two locations: Alexandria and Syene (now called Aswan), Egypt.
54 BCE – 30 CE The Roman Seneca devised the hydrologic cycle to show that, despite the inflow of river water, the level of the ocean remains stable because of evaporation.
ca. 150 CE The Greek Ptolemy compiled a map of the Roman World.
673–735 CE The English monk Bede published *De Temporum Ratione*, which discussed lunar control of the tides and recognized monthly tidal variations and the effect of wind drag on tidal height.
982 CE Norseman Eric the Red completed the first transatlantic voyage, discovering Baffin Island, Canada.
ca. 1000 CE Leif Eriksson, son of Eric the Red, established the settlement of Vinland in what is now eastern Canada.
1452–1519 Leonardo da Vinci observed, recorded, and interpreted characteristics of currents and waves, and he noted that fossils in Italian mountains indicated that sea level had been higher in the ancient past.
1492 Christopher Columbus rediscovered North America, sailing to the islands of the West Indies.
1500 Portuguese navigator Pedro Álvars Cabral discovered and explored Brazil.
1513 Juan Ponce de León described the swift and powerful Florida current.
1513–1518 Vasco Núñez de Balboa crossed the Isthmus of Panama and sailed in the Pacific Ocean.
1515 Italian historian Peter Martyr (Pietro Martire d'Anghiera) proposed an origin for the Gulf Stream.
1519–1522 Ferdinand Magellan embarked on a circumnavigation of the globe; Juan Sebastián de Elcano completed the voyage.
1569 Gerardus Mercator constructed a map projection of the world that was adapted to navigational charts.
1674 British physicist-chemist Robert Boyle investigated the relations among temperature, salinity, and pressure with depth and reported his findings in *Observations and Experiments on the Saltiness of the Sea*.
1725 Italian naturalist-geographer Luigi Marsigli compiled *Histoire Physique de la Mer*, the first book pertaining entirely to the science of the sea.
1740 Swiss mathematician Leonhard Euler calculated the magnitude of the forces that generate ocean tides and related them to the attractive force of the moon.
1770 Benjamin Franklin published the first chart of the Gulf Stream, which was used by ships to speed their passage across the North Atlantic Ocean.

1768–1771, 1772–1775, 1776–1780 Captain James Cook commanded three major ocean voyages, gathering extensive data on the geography, geology, biota, currents, tides, and water temperatures of all the principal oceans.
1802 American mathematician-astronomer Nathaniel Bowditch published the *New American Practical Navigator*, a navigational resource that continues to be revised and published to this day.
1807 President Thomas Jefferson mandated coastal charting of the entire United States and established the U.S. Coast and Geodetic Survey (now the Office of Coast Survey).
1817–1818 Sir John Ross ventured into the Arctic Ocean to explore Baffin Island, where he successfully sounded the bottom and recovered sea stars and mud worms from a depth of 1.8 km.
1820 London physician Alexander Marcet noted that the proportion of the chemical ingredients in seawater is unvarying in all oceans.
1831–1836 The epic journey of Charles Darwin aboard HMS *Beagle* led to a theory of atoll formation and later the theory of evolution by natural selection.
1839–1843 Sir James Ross led an expedition to Antarctica, recovering samples of deep-sea benthos down to a maximum depth of 7 km.
1841, 1854 Sir Edward Forbes published *The History of British Star-Fishes* (1841) and then his *Distribution of Marine Life* (1854), in which he argued that sea life cannot exist below about 600 m (the so-called azoic zone).
1855 Matthew Fontaine Maury compiled and standardized the wind and current data recorded in U.S. ship logs and summarized his findings in *The Physical Geography of the Sea*.
1868–1870 Sir Charles Wyville Thomson, aboard HMS *Lightning* and HMS *Porcupine*, made the first series of deep-sea temperature measurements and collected marine organisms from great depths, disproving Forbes's azoic zone.
1871 The U.S. Fish Commission was established with a modern laboratory at Woods Hole, Massachusetts.
1872–1876 Under the leadership of Charles Wyville Thomson, HMS *Challenger* conducted worldwide scientific expeditions, collecting data and specimens that were later analyzed in more than 50 large volumes of the *Challenger Reports*.
1873 Charles Wyville Thomson published a general oceanography book called *The Depths of the Sea*.
1877–1880 American naturalist Alexander Agassiz founded the first U.S. marine station, the Anderson School of Natural History, on Penikese Island, Buzzards Bay, Massachusetts.
1884–1901 USS *Albatross* was designed and constructed specifically to conduct scientific research at sea and undertook numerous oceanographic cruises.
1888 The Marine Biological Laboratory was established at Woods Hole, Massachusetts.
1893 The Norwegian Fridtjof Nansen, aboard the *Fram*, which had a reinforced hull for use in sea ice, studied the circulation pattern of the Arctic Ocean and confirmed that there was no northern continent.
1902 Danish scientists with government backing established the International Council for the Exploration of the Sea (ICES) to investigate oceanographic conditions that affect North Atlantic fisheries. Council representatives were from Great Britain, Germany, Sweden, Finland, Norway, Denmark, Holland, and Russia.
1903 The Friday Harbor Oceanographic Laboratory was established at the University of Washington in Seattle.
1903 The laboratory that became the Scripps Institution of Biological Research, and later the Scripps Institution of Oceanography, was founded in San Diego, California.
1912 German meteorologist Alfred Wegener proposed his theory of continental drift.
1925–1927 A German expedition aboard the research vessel *Meteor* studied the physical oceanography of the Atlantic Ocean, using an echo sounder extensively for the first time.
1930 The Woods Hole Oceanographic Institution was established on the southwestern shore of Cape Cod, Massachusetts.
1932 The International Whaling Commission was organized to collect data on whale species and to enforce voluntary regulations on whaling.
1942 Harald Sverdrup, Richard Fleming, and Martin Johnson published the scientific classic *The Oceans*, which is still an authoritative source.

1949 The Lamont Geological Observatory (later renamed Lamont-Doherty Earth Observatory) at Columbia University in New York was established.
1957–1958 The International Geophysical Year (IGY) was organized as an international effort to coordinate geophysical investigation of the Earth, including the oceans.
1958 The nuclear submarine USS *Nautilus* reached the North Pole under the ice.
1959 Bruce Heezen and Marie Tharp published the first comprehensive map of the Atlantic Ocean floor topography.
1959–1965 The International Indian Ocean Expedition was established under United Nations auspices to intensively investigate Indian Ocean oceanography.
1960 The bathyscaphe *Trieste* reached the bottom of the deepest (Mariana) ocean trench (10,915 m).
1964–1965 Hot, high-salinity brines and unusual black ooze sediments were discovered at the bottom of the Red Sea.
1966 The U.S. Congress adopted the Sea Grant College and Programs Act to provide nonmilitary funding for marine science education and research.
1968, 1975 The U.S. National Science Foundation organized the Deep Sea Drilling Program (DSDP) to core through the sediments and rocks of the oceans. Reorganized in 1975 as the International Program of Ocean Drilling, this program continues today.
1970 The U.S. government created the National Oceanic and Atmospheric Administration (NOAA) to oversee and coordinate government activities related to oceanography and meteorology.
1970s The United Nations initiated the International Decade of Ocean Exploration (IDOE) to improve scientific knowledge of the oceans.
1972 The Geochemical Ocean Section Study (GEOSECS) was organized to study seawater chemistry and investigate ocean circulation and mixing and the biogeochemical recycling of chemical substances.
1977 Research submersible *Alvin* makes the first visit to a hydrothermal vent and discovers an entirely new ecosystem based on chemosynthesis.
1977 Bruce Heezen and Marie Tharp published the first comprehensive map of the global ocean floor topography.
1978 *Seasat-A*, the first oceanographic satellite, was launched, demonstrating the utility of remote sensing in the study of the oceans.
1980s The Coordinated Ocean Research and Exploration Section program (CORES) was organized to continue the scientific work of the IDOE into the 1980s.
1980s The satellite-based Global Positioning System (GPS) was developed. It was made available for public use in 1983.
1990 The *JOIDES Resolution* drilling vessel retrieved a sediment sample estimated to be 170 million years old.
1990–2002 The World Ocean Circulation Experiment (WOCE) was conducted, in which 40 nations studied ocean circulation and its interaction with the atmosphere.
1992 The *TOPEX/Poseidon* satellite, which maps ocean surface currents, waves, and tides every 10 days, was launched.
1994 The Law of the Sea Treaty entered into force.
1995 The remotely controlled unmanned Japanese submersible *Keiko* set a new depth record of 10,978 m in the Challenger Deep of the Mariana Trench.
2000 The first autonomous float–based global ocean observation system (the *Argo* float) was put into operation, deployed as part of the Global Climate Observing System/Global Ocean Observing System (GCOS/GOOS).
2008 United Kingdom's National academy of sciences issues first report on ocean acidification and its possible effects on marine ecosystems.
2007 The three-thousandth *Argo* float was deployed to complete the inital ocean monitoring array. Equivalent to establishing the first global meterorological observation system.
2010 First publication of data showing that acidification of the oceans was already sufficient to cause harmful effects on marine life.

This textbook is made available as an open source textbook to avoid the high costs associated with commercial publishing. The textbook would sell through a publisher as an eBook for about $100 of which the author would receive only about 10%.

The costs of producing the text are entirely borne by the author. There is no obligation for anyone to pay anything for this text. However, if you find the text valuable and choose to, you may donate by clicking the Donate button below. The suggested donation is $10 (what the author would receive if sold for $100 through a publisher) but even a single dollar will help keep the book available for others.