CHAPTER II

PHYSICAL AND CHEMICAL PROPERTIES OF THE OCEAN

Terrestrial habitats exhibit extreme ranges in temperature and receive varying amounts of sunlight, precipitation, and wind. Additionally, they have other unique chemical and physical properties that make them suitable places for one species to live, but completely uninhabitable for another. So, too, oceanic habitats exhibit chemical and physical properties that make certain ocean zones suitable or unsuitable places for different species to live. In fact, chemical and physical properties of the ocean are crucial to the survival of marine organisms. This chapter addresses the chemical (salinity and dissolved gases) and physical (temperature, density, buoyancy, waves, tides, and currents) properties of ocean water that are delicately intermingled to produce one of the most self-sustaining life support systems on earth.

A. Salinity

The ocean is salty. But what makes it salty when the water flowing into it is from freshwater rivers, streams, and precipitation? Freshwater rivers and streams weather, or slowly wear away, the rocks and soils they flow over as they make their descent from mountainous and other inland regions toward the ocean. Rocks and soils release inorganic salts and other chemical compounds as they are weathered by this continuous flow of water. These inorganic salts and other chemical compounds are finally deposited in the oceans at the end of their journey from far away inland places. Additionally, precipitation causes fresh water and chemical compounds to be released from the atmosphere into the oceans.

Some of the inorganic salts and other chemical compounds become dissolved in the ocean water once they reach the ocean. Sodium (Na^+), chlorine (Cl^-), magnesium (Mg^{2+}), and calcium (Ca^{2+}) are inorganic salts that make up most of the solid material that has become dissolved in the oceans (Table 2-1). Ocean water is approximately 96.5% pure water and 3.5% naturally-occurring dissolved substances.

Table 2-1. Constituents of seawater.

Constituent	Symbol	% by Weight
chloride	Cl^-	55.1
sodium	Na^+	30.6
sulfate	SO_4^{2-}	7.7
magnesium	Mg^{2+}	3.7
calcium	Ca^{2+}	1.2
potassium	K^+	1.1
Total		**99.4**

Salinity is the term used to define the total amount of dissolved inorganic salts in the ocean. Salinity is measured, in most cases, in parts per thousand (ppt or ‰). For example, a salinity of 1‰, or 1 ppt, is equivalent to 1 gram of salt in 1,000 grams of pure water; a salinity of 30‰, or 30 ppt, is equivalent to 30 grams of salt in 1,000 grams of pure water.

There are a variety of different factors influencing the relative amounts of dissolved inorganic salts in the ocean. Sunlight, for example, causes only the fresh water part of the ocean to be evaporated, or absorbed by, the atmosphere, leaving only the inorganic salts behind. Frequent precipitation, on the other hand, adds fresh water back into the ocean system, thereby diluting the relative

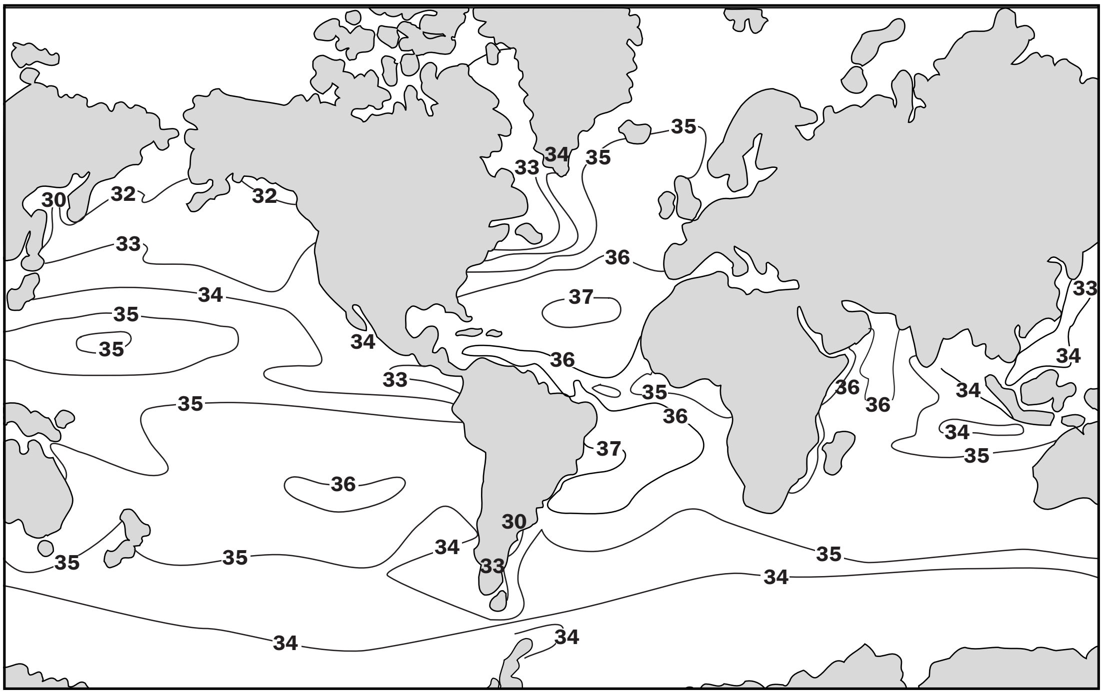


Figure 2-1.
Worldwide surface salinity distribution expressed in parts per thousand.

concentrations of inorganic salts in ocean water. Salinity can be varied by (1) changing the concentration of salts in the ocean, and/or (2) changing the concentration of water in the ocean. Rates of evaporation and precipitation can thus be related to salinity, with areas of generally high evaporation having high salinities and areas of high precipitation generally having lower salinities. Although the amount of dissolved inorganic salts varies among different areas of the world's ocean, the relative proportions of the inorganic salts themselves remain very similar throughout.

Salinities in the ocean range from less than 5‰ where rivers begin to reach coastal areas to as much as 45‰ in the saltiest oceans. The Black Sea has a relatively low salinity of 18‰, while salinities in the Red Sea, one of the saltiest seas in the world, range from 40 to 42‰. The salinity of open waters of the Atlantic Ocean averages 35‰, but may be as low as 15 to 25‰ in harbors, sounds, and bays, to about 30‰ along the coast. Salinity increases as the distance from shore increases, with salinities in continental shelf waters off the Southeastern U.S. ranging from 30 to 36‰, from 36 to 36.2‰ in the Gulf Stream, and from 36.2 to 37‰ in waters transported by currents from the Sargasso Sea.

The global distribution of sea surface salinities varies substantially (Fig. 2-1). This variability is mostly due to the relative amounts of precipitation and evaporation or the addition or removal of atmospheric fresh water. In tropical equatorial regions, evaporation is approximately equal to precipitation, and we observe a salinity of 34.5‰. Between latitudes 20 and 40˚ in both hemispheres, evaporation exceeds precipitation, resulting in high surface water salinities, reaching 35.7‰ (and higher). Near the polar regions (latitudes higher than 60˚ N and S), precipitation is significant and dilutes the seawater, resulting in much lower salinities (<33‰).

The salinity of different ocean areas is a major factor in determining the types of organisms capable of living there. As you will see in the following sections, interactions between salinity and temperature affect other physical properties of ocean water. Salinity also serves as one of the driving forces of major oceanic current systems, as discussed in Section H on page 29.

B. Temperature

Temperature is one of the most important physical factors affecting the distribution of life in the oceans. Additionally, temperature controls the rate at which organisms metabolize, or break down, food items into nutrients that they can use. Exchange of gases, such as oxygen (O_2) and carbon dioxide (CO_2), in the marine environment is greatly affected by temperature. Ocean temperatures also affect the survival of organisms as they develop through various life cycle stages, such as egg, larval, and juvenile stages.

Sea surface temperature in the ocean ranges from very warm in the tropics to below freezing in the polar regions. Oceanic waters become warmer as one moves toward the equator and conversely, cooler as one moves toward the poles. Ocean surface temperatures generally range from 0 to 30˚C (32 to 86˚F). Because salt lowers the freezing point of pure water, which is 0˚C (32˚F), ocean water freezes at about -1.1˚C (30˚F). Just as inorganic salts are left behind in the ocean water when freshwater is evaporated into the atmosphere, only the freshwater portion of the ocean surface freezes, thereby leaving the ocean water beneath the frozen surface layer saltier. The temperature of the Atlantic Ocean ranges from -2˚C to greater than 30˚C (28.4 to 86˚F) (Fig. 2-2).

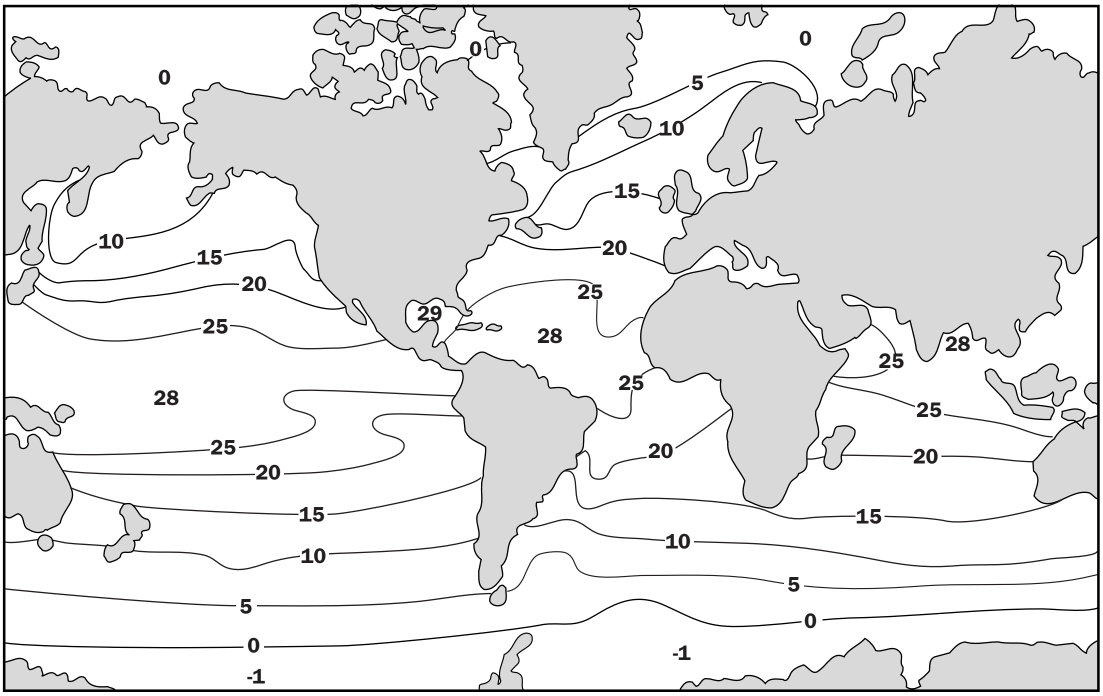


Figure 2-2. *Worldwide surface temperature distribution (in ºC).*

Surface temperatures in the ocean also vary seasonally, with the greatest differences in seasonal temperatures occurring near the poles. Temperatures remain relatively unchanged near the equator. Off the Southeastern U.S., ocean temperatures over the continental shelf can range from 9 to 25˚C (48 to 77˚F) at the surface and from 9 to 23˚C (48 to 73.4˚F) at the bottom during winter months to 27 to 30˚C (80 to 86˚F) at the surface and 20 to 28˚C (68 to 82˚F) at the bottom during summer months.

Generally, the deep ocean is very cold, and fewer organisms are capable of surviving these cold temperature extremes. But the recent discovery of hydrothermal vents along the ocean floor has revealed that heat is released from the earth's interior through fissures located on the ocean floor. These fissures and hydrothermal vents are most often located at the edges of divergent lithospheric plates (described in Chapter 1) and provide an oasis of warm water in the cold, deep ocean.

Most ocean waters have a subsurface temperature feature known as a thermocline. A thermocline is an area in the water column of the ocean where temperature changes very rapidly (Fig. 2-3). Thermoclines separate warmer surface waters from the cooler waters below. Because thermoclines are physical features that separate warmer waters from colder waters, they can be very effective barriers across which gases, nutrients, and in some cases, organisms, move. The vertical location of the thermocline can change seasonally.

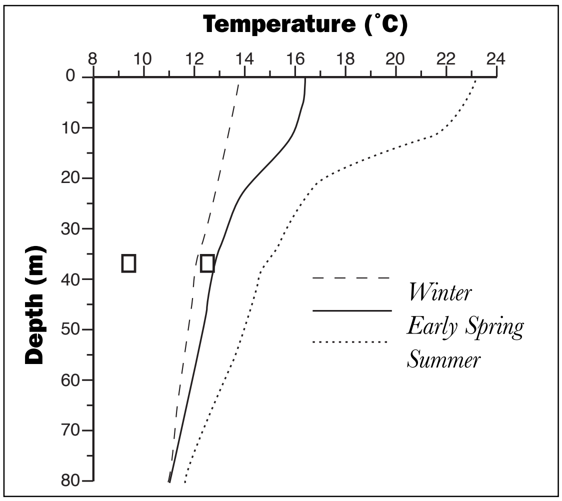


Figure 2-3.
Seasonal variability in the shape and depth of the thermocline.

C. Density

Variations in density, or the ratio of mass to volume, of the ocean are a function of salinity and temperature. Oceanic waters with higher salinities are more dense than oceanic waters with lower salinities. In other words, a liter of water with a salinity of 36‰ weighs more than a liter of water with a salinity of 32‰. Additionally, waters that have cooler temperatures have higher densities than waters with warmer temperatures. Ocean waters with higher salinities and cooler temperatures have the greatest densities. Dense water masses actually "sink" toward the ocean floor, while less dense ocean water masses "float" at or near the ocean's surface.

In coastal areas, fresh water in a river tends to flow toward the ocean along the river's surface, while the more dense salt water flows upstream along the bottom of the river (Fig. 2-4). The degree of mixing between the two water masses varies, depending on river flow, tides, wind, and the width and depth of the river as it approaches the ocean.

At the beginning of this chapter, we discussed that unique chemical and physical properties, like salinity and temperature, vary somewhat among the different ocean basins. Water masses from each ocean basin must ultimately meet since all of the major ocean basins are interconnected and form one global ocean. The ocean is, therefore, made up of "layers" of different water masses that are continually sinking toward the ocean floor or rising toward the ocean surface, depending on their indi-

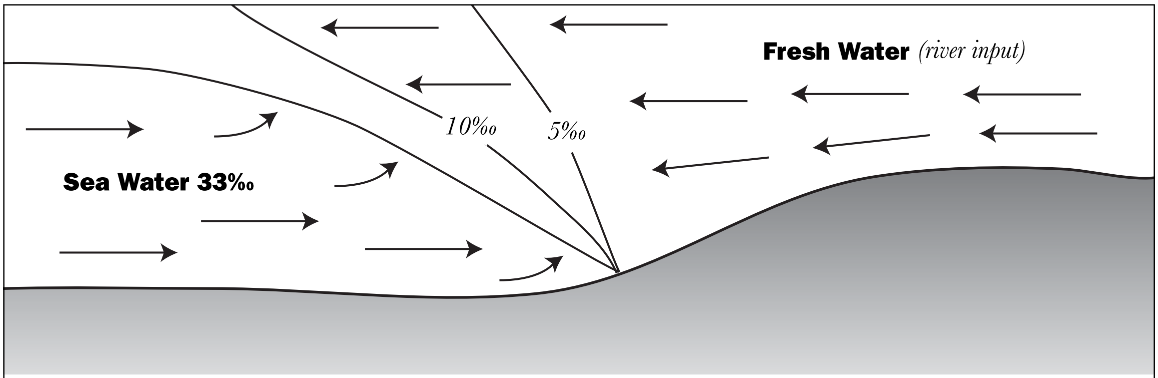


Figure 2-4. *Fresh water entering an estuary from a river is less dense than the salt water. In some estuaries, a wedge of denser salt water is created as the fresh water overrides denser water.*

vidual densities. It is the interactions among factors occurring at the ocean's surface, such as freezing, evaporation, precipitation, heating, and cooling, that determine the density of a certain water layer and thus, its vertical position in the "layered" global ocean.

D. Buoyancy

Just as water masses with different densities either sink below or float on top of one another, objects that are denser than water sink while objects that are less dense than water float. Buoyancy is defined as the ability to remain afloat in a liquid. Because salt water is more dense than fresh water, salt water provides greater buoyancy to an object floating on the surface than does fresh water. A person or a boat is more buoyant in salt water than in fresh water (Fig. 2-5). Denser liquids have a greater buoyancy force, or the force that makes an object float. In order for an object to float in a liquid, it must be less dense than that liquid.

Some organisms living in the ocean float on top of the ocean's surface. These organisms are very buoyant, or less dense, than the sea water in which they live, and most of their body mass is, in fact, made up of water. Some of these organisms have specialized structures that make them more buoyant, such as the balloon-like floats of the Portuguese man-o-

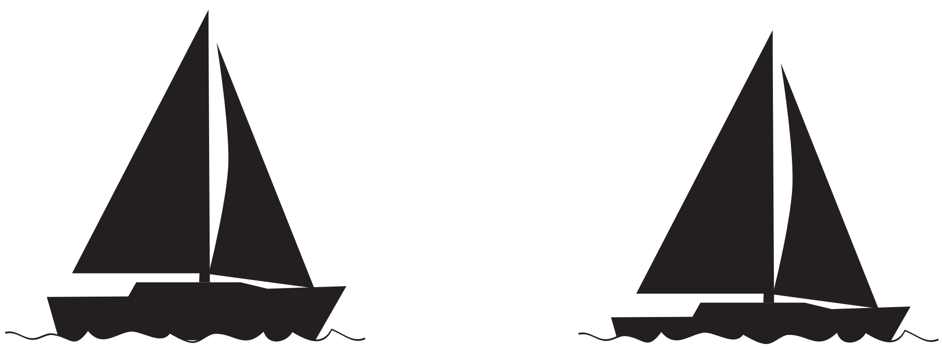


Figure 2-5. *An object is more buoyant in salt water than in fresh water.*

war or the air sacs of *Sargassum*, a brown alga common in the Sargasso Sea of the Atlantic Ocean (Fig. 2-6). *Sargassum* occasionally can be found washed ashore along the Southeastern U.S. coast. It can also frequently be found floating offshore in the Gulf Stream and makes up the "weed line" to which offshore fishermen often refer.

Oil floats on the surface of the water and many marine organisms produce an oil that makes them more buoyant. Even fish eggs may contain oil droplets, which enable them to remain at the surface or suspended in the water column. Increased body surface area and other unique adaptations, such as elongate spines and antennae, also retard the rate of sinking.

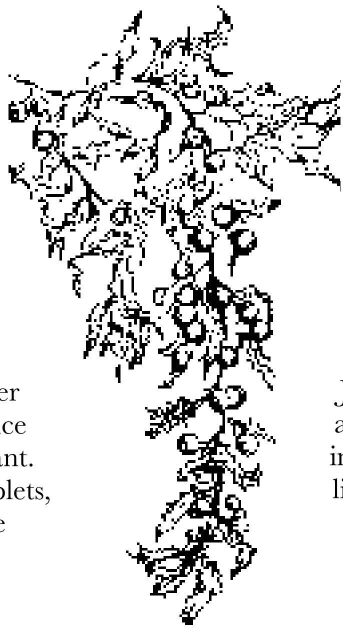


Figure 2-6.
Sargassum *is a buoyant brown alga found off the Southeastern U.S. coast.*

bicarbonate (HCO_3^-) for production of their protective shells. Other marine animals need oxygen (O_2) to breathe, and they give off carbon dioxide (CO_2) just as we do here on land. The ocean is the medium through which all of these nutrients and compounds are exchanged from organism to environment and back to organism again.

Just as organisms living on land are dependent on their surroundings for continued support of the life functions basic to survival, such as breathing and obtaining nutrients, so too are the organisms living in the ocean dependent on their surroundings for support of these same basic life functions.

E. Nutrient Uptake and Gas Exchange

The ocean provides a medium for uptake of nutrients and gases and elimination of wastes for all of the organisms living in it. Plants living in the ocean need "fertilizers," such as nitrate (NO_3^-) and phosphate (PO_4^{2-}), for continued growth and survival just as terrestrial plants do. Marine plants get nitrate and phosphate from the ocean water that surrounds them. Nitrate and phosphate are two limiting nutrients in the ocean environment, as the amount of primary productivity in various regions of the world oceans is directly related to the availability of each. Marine plants also need carbon dioxide (CO_2) to make their own food through the process of photosynthesis (See Chapter 3, Section D). The ocean is also the source of CO_2 for these plants.

Still other marine organisms need magnesium (Mg^{2+}), calcium (Ca^{2+}), silica [$Si(OH)_4$], and

F. Waves

Wind is a form of energy. Wind energy blowing along the surface of the ocean is transferred to the ocean as waves and currents (also see Section H). Waves originate in the open ocean and, in many cases, the waves we see along the coast were generated far away at sea (Fig. 2-7). The size of a wave depends on 3 factors: (1) the velocity of the wind, (2) the wind's duration, or the length of time the wind blows, and (3) fetch, or the distance of the ocean over which the wind is blowing. The harder the wind blows and the longer it blows, the greater its velocity and duration and the larger the waves. The longer the fetch, the larger the waves that are produced.

Waves can be so small that they are hardly noticeable. One of the largest waves ever recorded was 34 meters high (112 feet)!

Photo by CHERIE PITTILLO

Figure 2-7.
Plunging waves on a beach.

Earthquakes, submarine landslides, and volcanic eruptions also produce waves by displacing the water, thereby setting it in motion in the form of a wave.

There are different parts of a wave, each of which varies in size as the strength and duration of the wind varies. The highest part of the wave is called the crest and the lowest part of a wave is called the trough (Fig. 2-8). Wave height is the vertical distance between the levels of the trough and crest. Wavelength is the horizontal distance between the crests of two successive waves. Wave period is the length of time it takes a wave to pass a certain point. Wave velocity, or speed, can be calculated by dividing the wavelength by the wave period.

Because a wave is energy passing through water, the water through which the wave moves remains relatively still. The water moves in a circular motion as the wave passes through it. Alternatively, waves can move the water a great deal when they approach shorelines. As a wave approaches the shoreline, the depth of the water becomes shallower. The bottom of the wave is thus slowed down by friction as it begins to "feel" the bottom, but the top of the wave continues to move at its original speed. Also, the wave height increases as the water depth decreases. The wave then "trips," forming a breaker. An estimated 8,000 waves a day hit an average coastal beach. When ocean waves reach coastal shorelines, large amounts of energy are transferred from the wave to the beach and erosion of the land often takes place. Coastal erosion is discussed in more detail in Chapter 5. Nevertheless, waves can also transport and deposit sediment onto the shore, and thus serve to build certain shorelines.

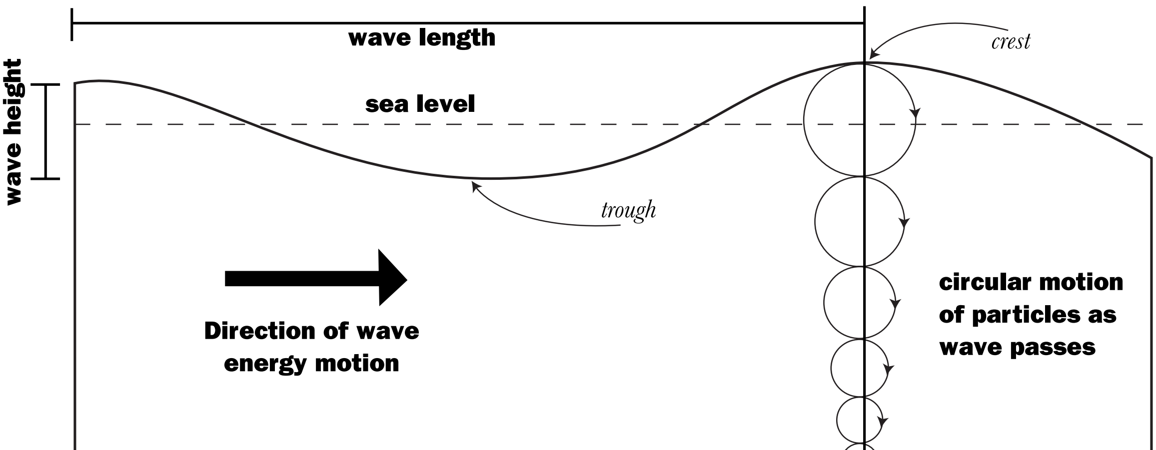
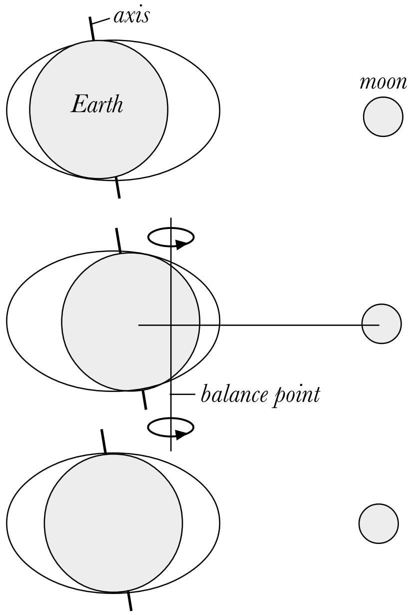


Figure 2-8.
Wave anatomy and oscillatory motion of particles within a wave.



a) Effect of gravitational force.

The gravitational pull on the earth by the moon causes a tidal bulge on the side of the earth that faces the moon.

b) Effect of centrifugal force.

The earth-moon system rotates around a "balance point," or axis for the moon's revolution around the earth. Centrifugal force creates a tidal bulge on the side of the earth that faces away from the moon.

c) Combined effects of gravitational and centrifugal forces.

Two tidal bulges result from the combined influences of gravitational and centrifugal forces.

Figure 2-9.
Gravitational (a) and centrifugal (b) forces between the earth-moon system contribute to the formation of two tidal bulges (c), one on each side of the moon.

G. Tides

Tides, or the periodic rise and fall of the ocean's surface, are caused by the gravitational pull of the moon and the sun on the earth. Because the moon is much closer to the earth than the sun, its gravitational pull on the earth is much greater than that of the sun. The moon's gravitational attraction "pulls" the ocean covering the earth's surface toward the moon, creating a bulge of water at the point on the earth directly facing the moon (Fig. 2-9a). We will refer to this bulge of water as a "tidal bulge."

There is a second tidal bulge on the side of the earth that faces away from the moon. This bulge is the result of the moon's revolution around the earth. Imagine a bowling ball ("earth") and tennis ball ("moon") that are connected by a short rod ("gravitational force"). Because of the mass differences of the balls, the balance point on the rod between them would be located much closer to the bowling ball. This balance point is analogous to the center, or axis, of the moon's revolution around the earth. Thus, as the moon revolves around this axis, centrifugal force causes water in the oceans to bulge on the side of the earth opposite the moon (Fig. 2-9b). If the moon had an ocean, it would also experience tidal bulges. The result of the combined gravitational and centrifugal forces is that there are always two tidal bulges on the earth, and they are always in alignment with the moon (Fig. 2-9c). The earth rotates underneath the bulges and the low-water areas between the bulges, giving the effect of rising and falling water we call tides.

Think of the tide as a large wave with crests on opposite sides of the earth. The wavelength of this large wave is more than 20,000 kilometers (12,600 miles), or one-half the circumference of the earth. As the earth rotates, a single point on it (for example, Charleston, South Carolina) moves underneath each of the two tidal crests (tidal bulges) of the large wave every day (Fig. 2-10). Hence the name semidiurnal (semi = half; diurnal = daily) tides. In other words, as Charleston moves under a tidal crest, it experiences a high tide. Alternatively, when Charleston is located in the troughs between each of these two tidal crests, it experiences low tides semidiurnally, or twice daily.

Tides are referred to in many ways. High tide is sometimes called flood tide. Low tide is referred to as ebb tide, and slack tide is the time just before the tide turns during which there is little tidal water movement. Flood and ebb tides may also be referred to as rising or falling tides, respectively. Tidal levels are also referred to as high or low, in or out, and up and down! A tidal cycle, the complete cycling from one low tide to the next low tide is generally half a day in length. Tidal periods are the times from low tide to high tide, and are generally six hours in length in South Carolina.

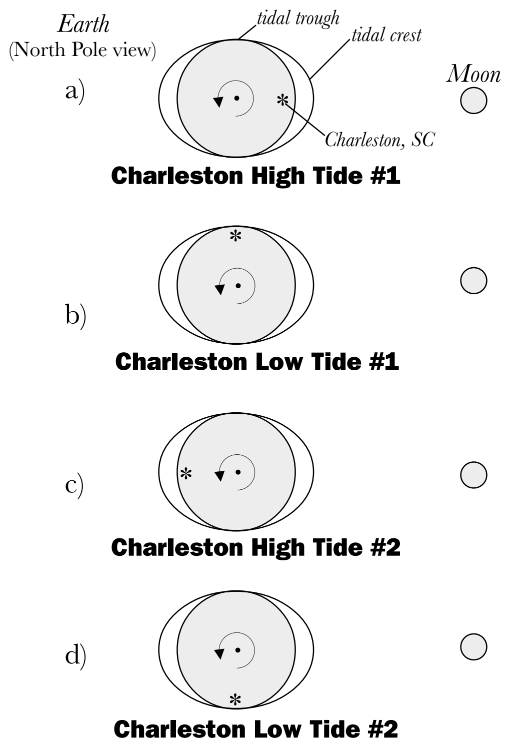


Figure 2-10.
During the day, Charleston, South Carolina rotates on the earth's axis and passes through two tidal crests (high tides) and two tidal troughs (low tides). This occurrence is known as a semidiurnal tide.

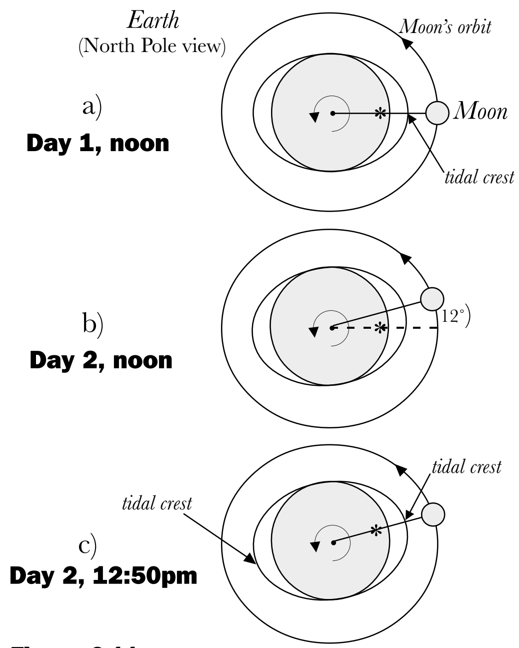


Figure 2-11.
Why is high tide approximately 50 minutes later each day? The moon continually travels in its orbit around the earth. Each day a point on Earth, such as Charleston, South Carolina, has to "catch up" to the position of the tidal bulge that has advanced 12° along the moon's orbit. This catch-up takes approximately 50 minutes, thus delaying high tide.

High and low tides do not occur at the same time every day. They instead occur approximately 50 minutes later each day. To explain this, let's use the following example. Charleston experiences a high tide at 12:00 noon on Day 1 (Fig. 2-11a). At 12:00 noon on Day 2, high tide has not yet occurred in Charleston and will not occur until 12:50 p.m., almost a full hour later. As you know, earth makes a

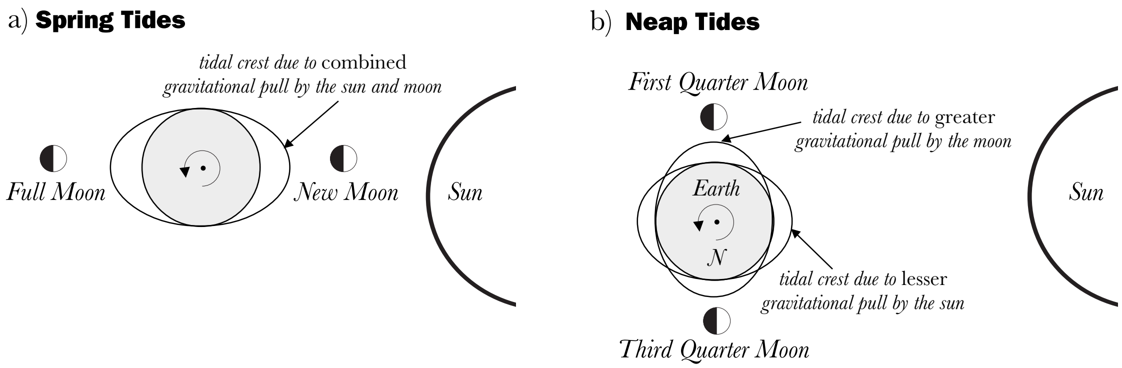


Figure 2-12.

(a) Spring tides are the result of two combined tidal crests from the moon and sun. The effect is to accentuate the difference between high and low tides. (b) Conversely, neap tides are the result of two opposing tidal crests from the moon and sun. The effect is to dampen the difference between high and low tides.

complete rotation on its axis every 24 hours. During this 24-hour period, the moon advances in its own orbit around the earth by 12° degrees of the orbit (Fig. 2-11b). Correspondingly the tidal crests, which as you will remember, are always in alignment with the moon, also advance with the moon 12° degrees. Thus, at noon on Day 2, Charleston is not underneath the tidal crest which caused the high tide at 12:00 noon on Day 1. The time of the mid-day high tide on Day 2 in Charleston occurs approximately 50 minutes later, as it takes approximately 50 extra minutes for Charleston to "catch up" with the tidal crests (Fig. 2-11c). Remember, since Charleston experiences semidiurnal tides, the amount of time between two successive high tides is only 12 hours and 25 minutes, or half of the 24 hours, 50 minutes.

Tidal range is the vertical difference in the height of the water between high and low tides. Ranges vary worldwide, from less than 30 cm (1 foot) in some places to over 15 meters (50 feet) in the Bay of Fundy, Nova Scotia. When the earth, moon, and sun are in alignment, tidal ranges are greater than average due to the added gravitational pull on the ocean's surface by the sun. These greater than average tidal ranges occur twice a month, during new and full moons, and are called spring tides (Fig. 2-12a). Conversely, when the moon is at a right angle to the sun and earth, the earth experiences neap tides, or smaller than average tidal ranges (Fig. 2-12b). During a neap tide the moon's gravitational pull is at right angles to the sun's lesser gravitational pull. Two tidal crests result and serve to diminish the difference between high and low tides. Neap tides, like spring tides, occur twice a month, during the first and third quarter moons.

Tidal ranges have been classified into three groups: microtidal, mesotidal, and macrotidal. These groupings were originally defined using the measurement unit of feet rather than meters. We refer to tidal ranges between 0 and 6 feet as microtidal; between 6 and 12 feet as mesotidal; and greater than 12 feet as macrotidal.

Along the Southeastern U.S. shoreline, tidal range varies considerably. From Cape Hatteras, N.C. to Bull Bay, South Carolina, spring tidal ranges are microtidal, whereas the range from Bull Bay to Savannah, Georgia is classified as mesotidal. Portions of the Georgia

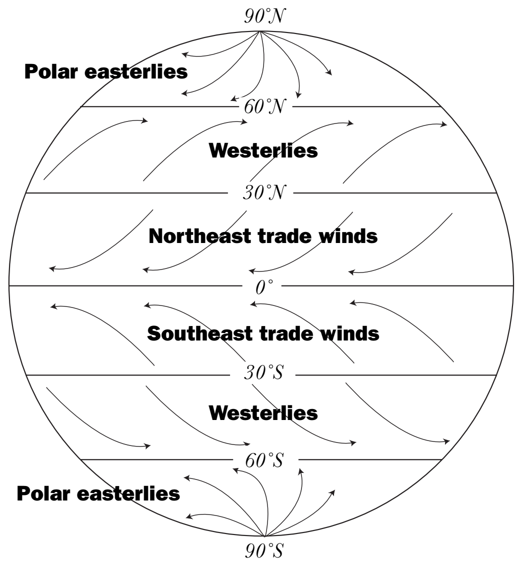


Figure 2-13.
Global wind patterns.

coastline have tidal ranges of 9 feet and more. The relative influences of waves and tidal currents have a strong control on the shape, or morphology, of the coastline, and will be discussed in Chapter 4.

As you will see in Chapters 3 and 4, organisms living in intertidal areas, or areas that are exposed to air during low tides, have developed special adaptations that enable them to live underwater during high tide, and completely exposed during low tide.

H. Oceanic Currents

Movement of water along the surface of the open ocean, known as surface current circulation, is primarily caused by wind. Surface currents are slow, broad currents, the effects of which can extend to depths of 200 m (656 feet). Alternatively, density drives deep ocean currents to create thermohaline (temperature- and salinity-driven) circulation. Thermohaline circulation is much slower, and it has been estimated that it would take several hundred years for dense water that sinks in the North Atlantic to surface again in the Southern Hemisphere. Ocean currents, whether wind-driven surface currents or density-driven thermohaline circulation, are major factors determining the distribution of life on earth, as many of the early life history stages of marine organisms are transported far from their points of origin to new locations by ocean currents. Ocean currents also have major effects on weather patterns throughout the world.

1. Surface Currents

The major surface currents are driven by three latitudinal bands of winds: 1) the Trade Winds, which blow from east to west at about 20° Latitude (North and South); 2) the Westerlies, which blow from west to east along the 40-50° latitudes; and 3) the Polar Easterlies, which blow from east to west in the polar regions (Fig. 2-13). As ocean surface water is blown by the wind, the water does not move parallel to the wind. Instead, the earth's rotation causes surface waters to be deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This phenomenon of deflection, or "bending" of currents, is known as the Coriolis effect.

Large circular surface currents, known as gyres, also occur in the open ocean and rotate in a clockwise direction in the Northern Hemisphere and in a counter-clockwise direction in the Southern Hemisphere. The North Atlantic Gyre rotates in a clockwise direction in the Atlantic Ocean (Fig. 2-14).

Each surface current has its own unique temperature, salinity, density, directional flow, speed, and well-defined boundaries between adjacent currents. The Gulf Stream off the Southeastern coast of the U.S. is one of the most well-known and well-studied surface currents. In fact, Benjamin Franklin mapped the Gulf Stream, an incident that is often cited

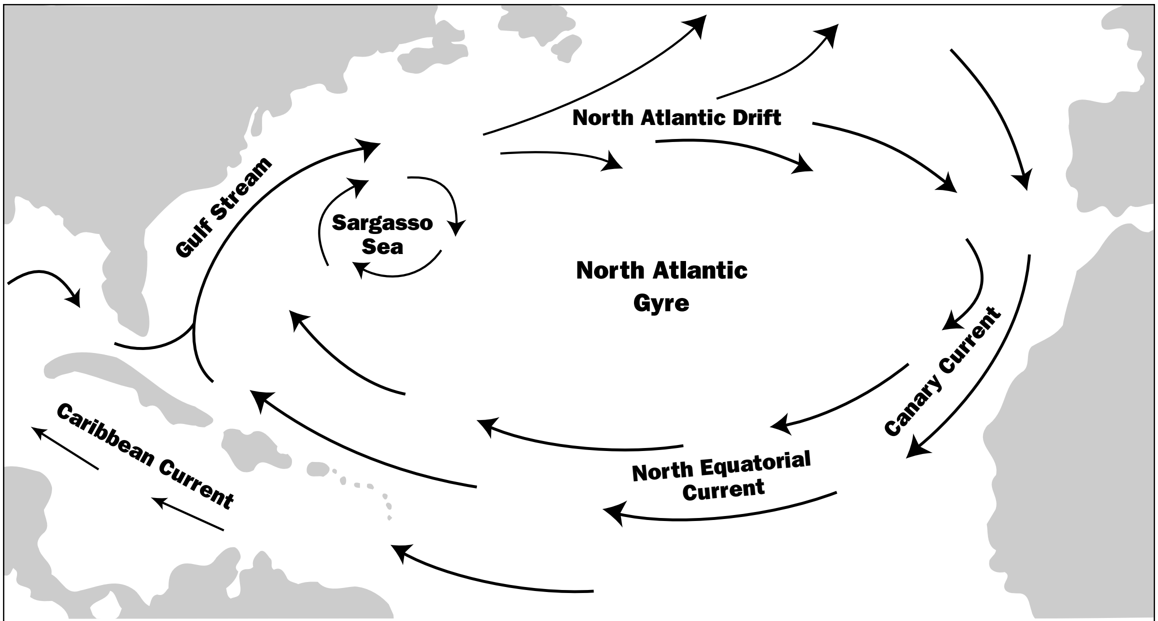


Figure 2-14. *North Atlantic surface currents.*

as the beginning of ocean science studies in the United States. The width of the Gulf Stream varies from 80 to 241 kilometers (50 to 150 miles) and its depth varies from 456 meters to 1,523 meters (1,500 to 5,000 feet). The Gulf Stream flows at a speed of 4.8 kilometers to 9.7 kilometers (3 to 6 miles) per hour, transporting 63.5 million metric tons (70 million tons) of water every second. The Gulf Stream is actually the western segment of the North Atlantic Gyre (Fig. 2-14). Along its northward journey, the Gulf Stream often weaves back and forth in s-shaped curves. These curves are referred to as meanders. Sometimes these meanders are so pronounced that they "pinch off" from the main current and depart as small rings of the Gulf Stream, known as eddies.

As the Gulf Stream flows northward along the Eastern Atlantic coast, it comes within 40 kilometers (24 miles) of portions of the Southeastern U.S. coast, carrying warm tropical waters with it. Beautiful, brightly colored tropical species of plants and animals that have been transported northward from the Caribbean are frequently found living far north of their original habitat. As the Gulf Stream moves northward along the East coast of the United States, the Coriolis effect causes it to be deflected toward the east where it crosses the Atlantic. At this point, the Gulf Stream becomes the North Atlantic Drift Current (Fig. 2-14). Because the North Atlantic Drift Current contains warm Gulf Stream water, it warms the British Isles.

2. Thermohaline Circulation

Thermohaline circulation is caused by the vertical movement of water as a result of temperature and salinity differences. Thermohaline circulation is the major factor driving deep ocean current patterns. As we discussed at the beginning of this chapter, cold dense water masses will sink below layers of ocean water. This phenomenon of "sinking" water layers, or downwelling, drives thermohaline circulation in the deep ocean. It is the combination of salinity and temperature of a particular water mass that determines its vertical position, or the depth to which it "sinks," in the water column. This sinking of cold, dense water masses must be balanced by rising water masses elsewhere.

Upwelling is the mechanism by which deep ocean waters rise toward the surface. Upwelling in the open ocean is in part driven by thermohaline circulation which displaces and "pushes" bottom waters upward as the denser water masses sink to the bottom. The upwelled bottom waters are rich with nutrients that have accumulated from the constant rain of recycled material to the sea floor. These nutrients enter the photic zone and microscopic plant life flourishes, providing food for a vast number of animals living in surface waters.

Thermohaline circulation in the Atlantic Ocean results in the formation of two distinct deep ocean water mass currents: the North Atlantic Deep Water (NADW) and the denser Antarctic Bottom Water (AABW). These two currents are formed by very cold, salty water and originate at the poles. The AABW sinks near the coast of Antarctica and travels northward (Fig. 2-15), hugging the seafloor. The NADW sinks in the Arctic and travels southward where it eventually meets the AABW. Because the AABW is the denser of the two water masses it moves underneath the NADW. The NADW continues to travel southward, but it "rides" over the AABW and a portion of the water mass eventually upwells in the Antarctic Ocean where it joins the surface current circulation. The other portion veers to the east and continues its trek into the Indian and Pacific Oceans.

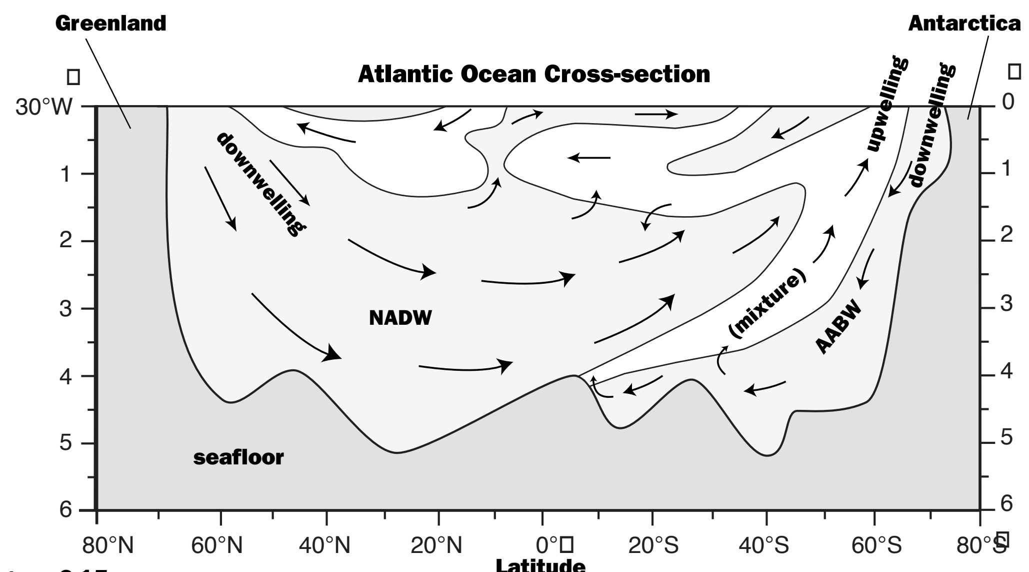


Figure 2-15.

Simplified drawing of density–driven, thermohaline circulation of the North Atlantic Deep Water (NADW) and the denser Antarctic Bottom Water (AABW).