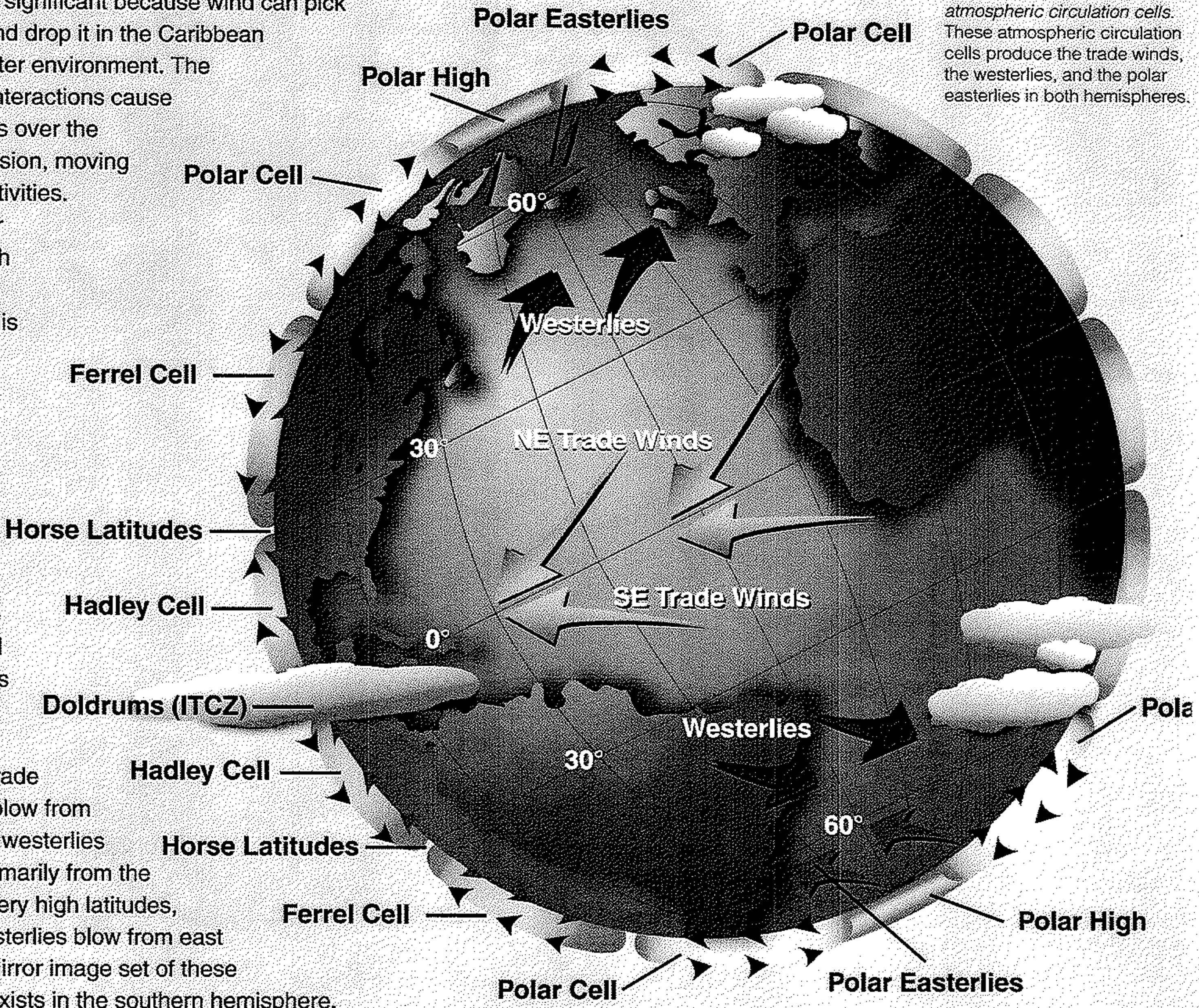
The Ups and Downs of the Seas

Today's scientists realize that the air, land and sea constantly exchange material and energy. This is significant because wind can pick up dry Sahara desert soil and drop it in the Caribbean Sea, changing the underwater environment. The dynamics of these energy interactions cause water to move in many ways over the earth's surface, causing erosion, moving soil and affecting human activities.

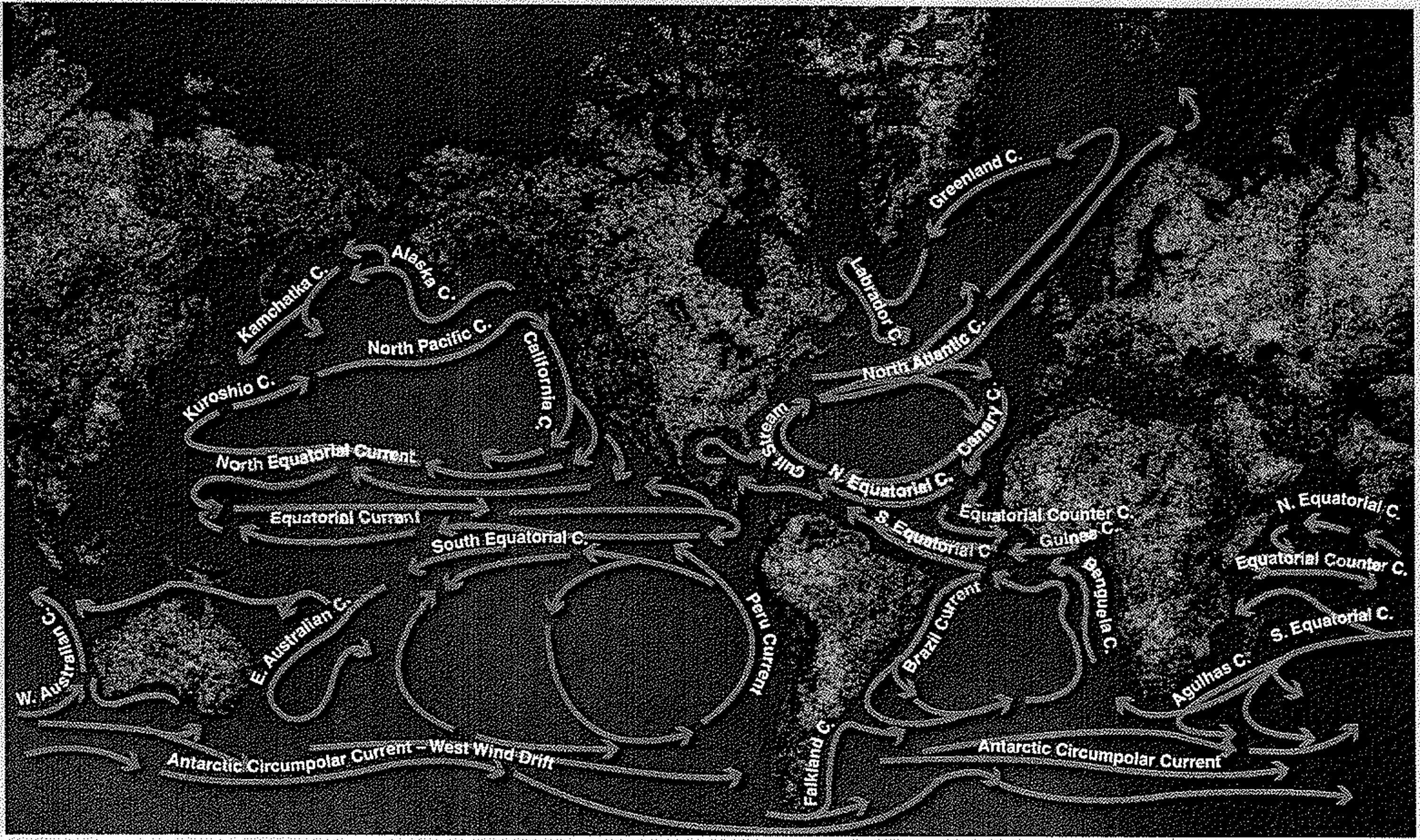
A primary cause of water motion is wind energy, which transfers to the water as it blows across its surface. This results in two primary types of water motion: currents and waves, both of which can result from forces other than wind as well.

SURFACE CURRENTS

When winds blow over large areas with reasonable consistency of direction and strength, significant volumes of water move horizontally across the oceans. In the northern Hemisphere, the trade winds (near latitude 15°N) blow from northeast to southwest; the westerlies in the mid-latitudes blow primarily from the southwest. At very high latitudes, the polar easterlies blow from east to west. A mirror image set of these wind belts exists in the southern hemisphere.



Global wind patterns are divided into six regions (three in each hemisphere) called *atmospheric circulation cells*. These atmospheric circulation cells produce the trade winds, the westerlies, and the polar easterlies in both hemispheres.

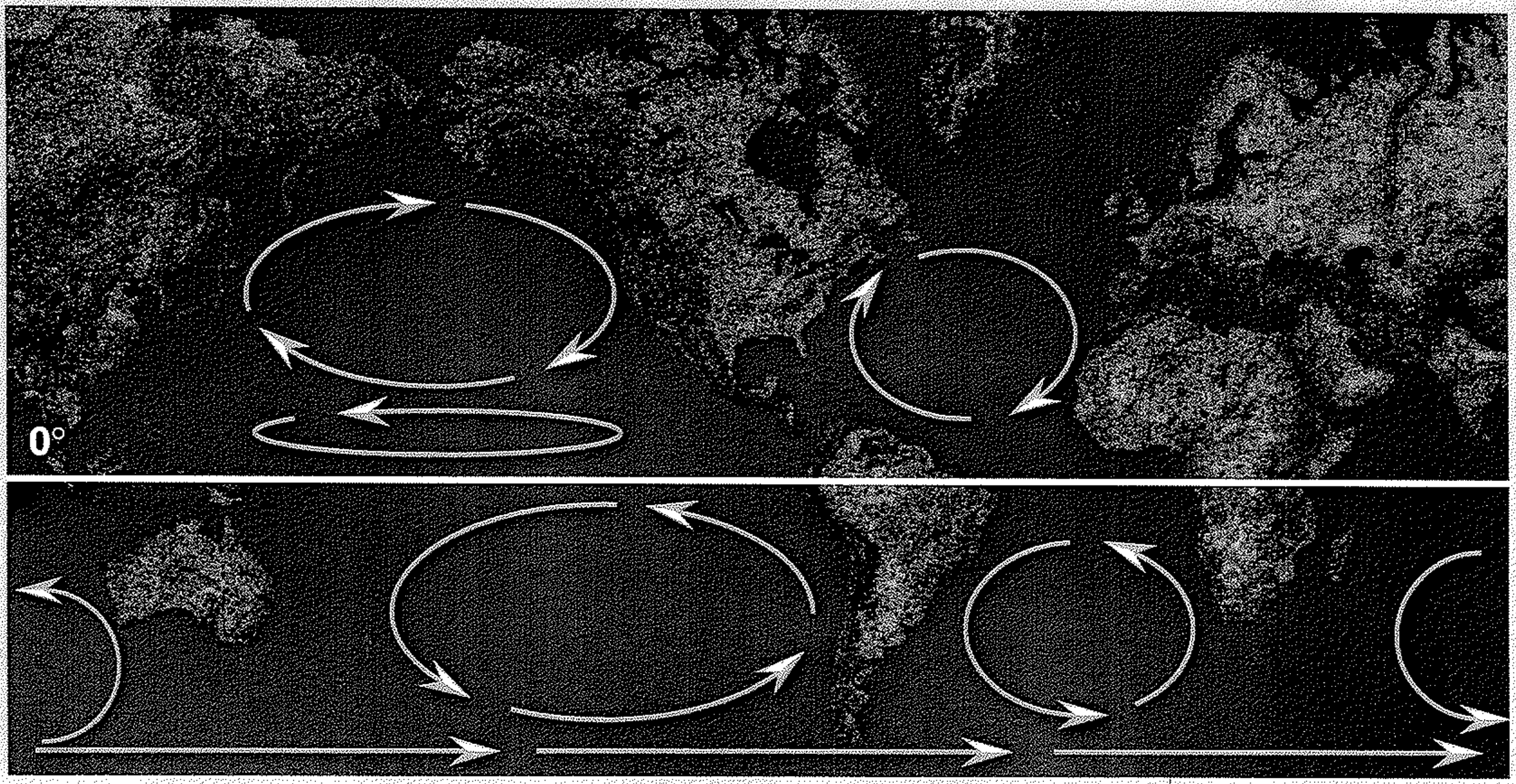


The major currents of the world's oceans.

The energy from these wind systems drives the major surface ocean currents. Some of these currents transport more than 100 times the volume of water carried by all of the earth's rivers combined. As with a wind-driven wave, surface current speed diminishes rapidly with depth, becoming negligible at depths around 190 metres/600 feet.

The earth's rotation also affects the major ocean currents. This is termed the *Coriolis effect*, and explains why objects in the northern hemisphere deflect to the right of the direction of the force acting on them (in this case, the wind is the force and the object is the water's surface). The opposite is true in the southern hemisphere. There, objects deflect to the left of the direction of force. The result is that water tends to pile up in the middle of the ocean basins as the major ocean currents travel along their edges according to the Coriolis effect. These

Coriolis Effect



Major ocean gyres. The Coriolis effect causes the major currents to deflect to the right in the northern hemisphere and to the left in the southern hemisphere. In this way, the Coriolis effect creates circular airflow and current patterns, including the major ocean gyres.

circular water movement patterns are called *gyres* and play major roles in global heat and marine life distribution.

Currents occur in oceans, but also in large lakes, seas and even smaller water bodies to some extent. However, the smaller the water body, the stronger the wind must be to develop a current of a given strength because there's less surface area across which to transfer energy. However, many large lakes have sufficient area to generate significant currents (and waves).

WAVES

Waves range in size from a fraction of an inch for small, surface capillary waves to towering storm waves more than 30 metres/100 feet high. They are more complex than they appear.

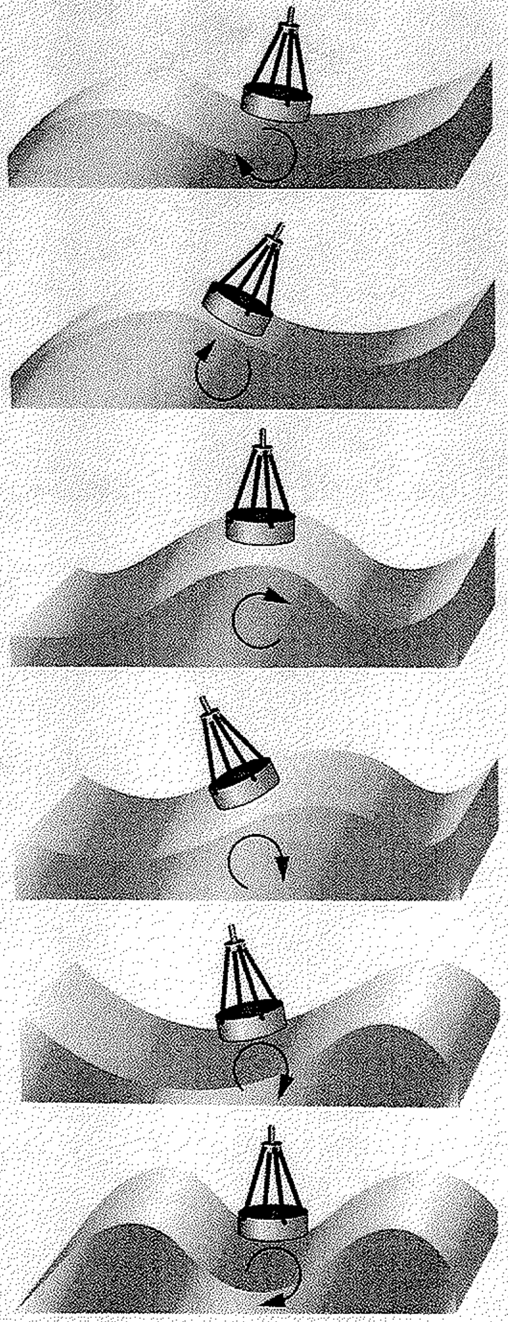
A *wave* is the transmission of energy through matter. When energy moves through matter as a wave, the matter moves back and forth or rotates, but then it returns to its original position. It transmits the energy to adjacent matter, allowing the energy to continue. For instance, imagine dropping a stone in a pond. Waves ripple away from the splash. The water doesn't move away, only the energy.

As you watch the rippling, you can see the energy move as a series of waves away from the disturbance as a *progressive wave*. It's called a progressive wave because you can see the energy progress from one point to another. There are three types of progressive wave – longitudinal, transverse and orbital.

A *longitudinal wave* occurs when the matter moves back and forth in the same direction that the energy travels. This type of wave can move through all states of matter, transmitted through the compression and decompression of particles, much like a spring. Sound is a longitudinal wave

When *transverse waves* occur in matter, the motion of the matter is perpendicular to the direction in which the wave as a whole is moving. For example, when you shake one end of a taut, horizontal rope up and down, the rope moves vertically, but the wave travels horizontally along the length of the rope.

Orbital waves only transmit through fluids. With respect to the ocean, these are primarily the waves that concern us. They occur when the energy moves the fluid in a circular motion as it passes. Imagine a floating buoy. As the wave approaches, the buoy moves forward on the wave face. It rises, goes over the crest, and slides backward down the rear of the wave.



Orbital wave motion. As the wave approaches, the buoy moves forward on the wave face. It rises, goes over the crest, and slides backward down the rear of the wave. Individual particles of water move in circular patterns (shown by curved arrow) as the wave's energy moves through the water.

Although the water (fluid) travels through orbital motion, it returns to its original place. Only the energy moves on. Looking at the buoy in the illustration, it looks like the orbital motion occurs only in a single plane. Actually, the orbital motion continues in progressively smaller orbits down to a depth of about half the wave's *wavelength* – the horizontal distance between the identical point on two waves, such as crest to crest.

You can express wave characteristics mathematically. This is useful because it allows you to calculate wave behaviors based on the information you have. H:L is the ratio of the wave height to wavelength. If you know the wavelength (L: depth in metres) and the period (T: time in seconds), you can determine the speed (S: speed in metres per second) of ideal *deepwater waves*, i.e. waves in water deep enough that the bottom doesn't affect them (more about these shortly).

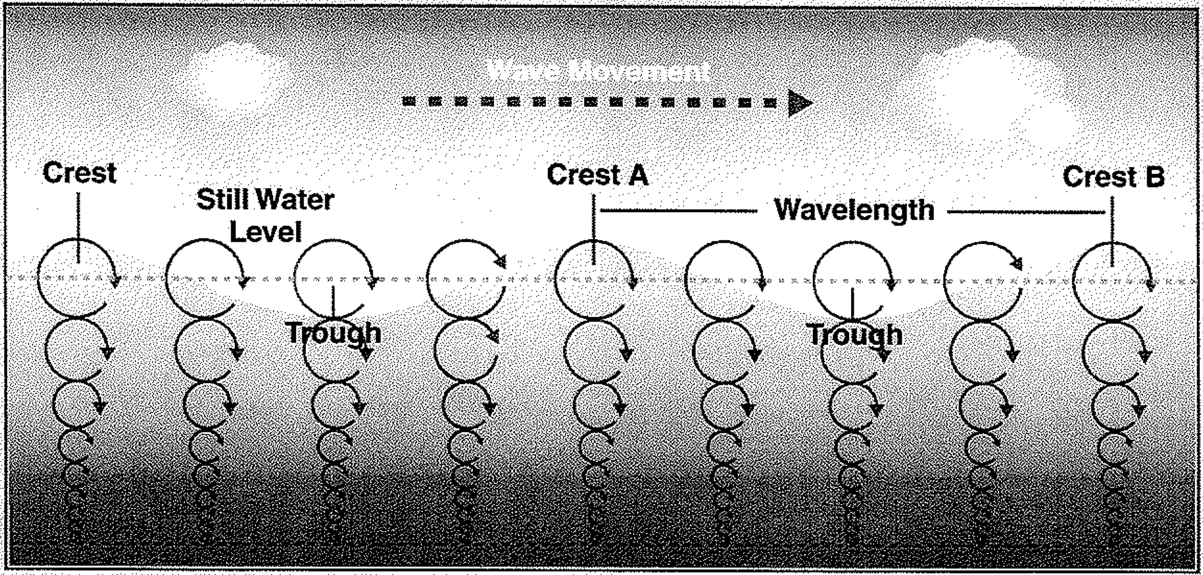
This results in the formula:

speed = wavelength ÷ period

or

$$S = L \div T$$

However, keep in mind that this equation, while useful, doesn't account for other factors that influence deepwater wave speed, nor the speed of a wave when it reaches shallow water.



Negligible Water Movement Below 1/2 Wavelength

Major wave components and orbital pattern. The *wavelength* is the horizontal distance between the identical points on two waves—in this illustration the horizontal distance from A to B. The *crest* is the highest wave point above the average water level. The *trough* is the lowest point, and the *height* is the vertical measurement from the trough to the crest. *Period* is the time it takes for the same spot on two waves to pass a single point, while *frequency* is the number of waves that pass a fixed point in one second. Note the orbital wave pattern tapering in intensity down to a depth equal to one half the wavelength.

Wave Causes and Characteristics. Let's look at what causes waves and how they behave in the real world. *Disturbing forces* cause waves and *restoring forces* resist them. The intensity and duration of a disturbing force and the interaction of restorative forces give waves their characteristics.

Fluids tend to remain at rest on the earth. They only move when something imparts energy to them – disturbs them. Disturbing forces that cause ocean waves include wind, changes in gravity, and seismic activity. Wind is the most common disturbing force through the friction of air passing over the water's surface. Changes in gravity cause a wave you probably don't think of as a wave – the tides. These have characteristics that distinguish them significantly from what we normally think of as waves, so we'll look at them separately. Seismic activity includes earthquakes and volcanic eruptions, which can cause tsunamis.

Each kind of disturbing force tends to produce waves with distinct wavelengths. Wind commonly creates wavelengths of about 60 to 150 metres/200 to 500 feet. The wavelength of the tides is about the size of the ocean basins, and tsunamis have wavelengths of about 200 kilometres/120 miles.

Gravity is the main restoring force for large waves and seismic waves. It tends to flatten waves by pulling water back to level. Gravity and the Coriolis effect are the primary restoring forces for the tides, because their wavelengths are so long. Surface tension is an important restoring force for the tiniest waves, called *capillary waves*, which have wavelengths of about 1.7 centimetres/0.7 inches or less. Surface tension is caused by the strongly polar nature of bonds in water, which resists surface disturbances. You'll learn more about surface tension in Chapter Four.

You can classify waves based on which restoring force has the most effect. Capillary waves are classified as such because the primary force countering them is surface tension. Capillary waves are the first to form as wind blows across still water. As waves grow larger, however, surface tension becomes relatively insignificant as a primary restoring force. Gravity – the weight of the wave – takes over, so we call large waves gravity waves. For practical purposes, most of the waves that concern us while diving are *gravity waves*.

Although disturbing forces can be somewhat random in their intensity, duration, and place of origin, waves tend to organize themselves into patterns. Waves that are not so organized travel at different speeds. The longest waves outrun the smaller ones. Eventually only waves of similar wavelengths are left traveling together. They are called *swell*, which is simply the rise and fall of a uniform wave pattern on the sea.

Groups of swells with similar

Wavelengths and Disturbing Forces of Important Ocean Waves

Wave Type	Primary Standard Wavelength	Primary Disturbing Force	Restoring Force
Wind wave (capillary)	Less than 1.73 centimetres	Wind	Surface tension
Wind wave (gravity)	Up to 150 metres	Wind	Gravity
Seismic wave	200 kilometres	Seismic activity	Gravity
Tide	Up to 17,000 kilometres	Sun and moon	Gravity and Coriolis effect

Wavelengths and disturbing forces of important ocean waves.

characteristics tend to travel together in *wave trains*. The first wave in the train gradually loses energy, which is picked up by new waves forming in the trailing portion of the train. As the leading waves dissipate, the trailing waves form and join the train. The entire train moves at half the speed of individual waves through this process of dissipation and reformation. When the wave train reaches shallow water, the individual and group speeds become the same. This is because depth affects wave characteristics, leading to the concepts of *deepwater waves* and *shallow-water waves*.

Deepwater waves occur in water that is deeper than half their wavelength. Water motion in orbital waves decreases very quickly with depth. If the water is deeper than half the wavelength, then no interaction with the bottom can affect the wave characteristics. A fish swimming at 20 metres/66 feet wouldn't notice effects from a wave passing overhead if the wavelength is 40 metres/130 feet or less. Because the bottom doesn't affect deepwater waves, their orbital motion progresses unaffected.

When the water is shallower than one-fourth the wavelength, the bottom creates drag that affects the orbital motion. This tends to flatten the circular motion into an ellipse. When the depth is about one-twentieth of the wavelength, the wave becomes a shallow-water wave. In depths between one-half and one-twentieth the wavelength, waves are transitional, progressing from deepwater to shallow-water characteristics.

Deepwater and shallow-water waves can exist at the same time. A good example is the giant wave created by the tides. By definition, this is always a shallow-water wave because the wavelength is about the size of its ocean basin. For a tide to be a deepwater wave, the ocean would have to be deeper than the diameter of the earth! The wind creates waves, which can be deepwater waves on top of the tides. Capillary waves are almost always deepwater waves because the water only needs to be 0.9 centimeters/0.35 inches deep.

As previously mentioned, wind waves grow due to friction with the air transferring energy to the water. As a wave grows, it presents a larger surface area to the wind, allowing more energy to transfer. The three factors that affect the growth of a wind wave are wind speed, wind duration, and *fetch*.

Wind speed is important because the wind must be blowing faster than the wave to give it energy. Wind duration is the length of time the wind blows in a single direction. Even a high-speed wind won't cause large waves when the duration is short or the direction makes frequent significant changes. *Fetch* is the surface area over which the wind blows. A small pond will never have huge waves, even with a high-speed wind blowing for hours, because there's not enough surface area to transfer the required energy to form a big wave.

The combination of these three factors yields a maximum theoretical wave size. Above this theoretical maximum, the disturbing forces and restoring forces counterbalance so waves can't grow any larger. When an area has reached the maximum size, it is called a *fully developed sea*. With wind speed, duration, and fetch all acting as independent variables, a fully developed sea isn't necessarily a large sea. Average wave heights for fully developed seas range from about a quarter of a metre (almost a foot) to about 15 metres/50 feet.

As in the example of the small pond, these three factors also influence the largest waves that an ocean can have. Remember that an ocean often has large, unobstructed stretches of water over which wind waves can develop.

Perhaps surprisingly, at times a wave can be larger than the maximum theoretical size for a fully developed sea. Scientists believe such a *rogue wave* results from the interaction of two closely related wave trains. When wave trains come together from different areas, they affect each other in the form of *constructive* or *destructive* interference. If the waves are *in phase*, the crests and troughs coincide so the wave's heights are constructive and combine to make larger waves. Also, anomalously large waves can result when waves go against the direction of a current, which makes the waves steeper. This second mechanism is probably a more important cause of rogue waves.

If wave trains are *out of phase*, so that the crests of one train coincide with the troughs of the other, the waves cancel each other out. Neither constructive nor destructive interference can act over distances greater than a few wave lengths. Therefore, for example, destructive interference cannot result in a relatively calm sea during strong winds.

It's relatively rare for trains coming together to have exactly the same wavelength and to be synchronized. They're usually timed slightly differently, and interacting trains tend to alternate between being constructive and destructive. This results in a mixed sea with periods of large and small waves. You've probably seen surf patterns that cycle from periods of calm, build to large waves, then regress to calm again, and so on. This is the effect of two slightly different wave trains coming together.

SURF AND BREAKING WAVES

If you've ever been to the beach, you've seen waves break and spill their energy as surf. Have you ever thought about *how* a wave breaks?

In deep water, a wave breaks when its H:L ratio exceeds 1:7. That is, when the height exceeds one-seventh of the wavelength, the wave breaks as whitecaps. The same ratio applies in shallow water, though through a different process.

Deepwater waves become transitional when they enter water that's shallower than half their wavelength. At this point, the bottom begins to affect the wave. As it moves shoreward, the orbital motion flattens, becoming elliptical. Interaction with the bottom slows the wave, decreasing the wavelength and packing the wave's energy into a tighter area. This causes the wave height to rise.

As the wave continues moving shoreward, the wavelength continues to decrease and the height continues to increase, moving the wave closer and closer toward an H:L ratio of 1:7. The wave passes the 1:7 ratio when the depth is 1.3 times the height. Because the crest of the wave is now traveling faster than its trough, and because its height is more than 1.7 times its length, the wave becomes unstable. The instability causes the wave to break, and its crest topples forward.

There are three basic types of wave break. *Plunging breakers* are characterized by a curl as the top of the wave pitches through the air before splashing into the bottom. These occur

Plunging breaker.

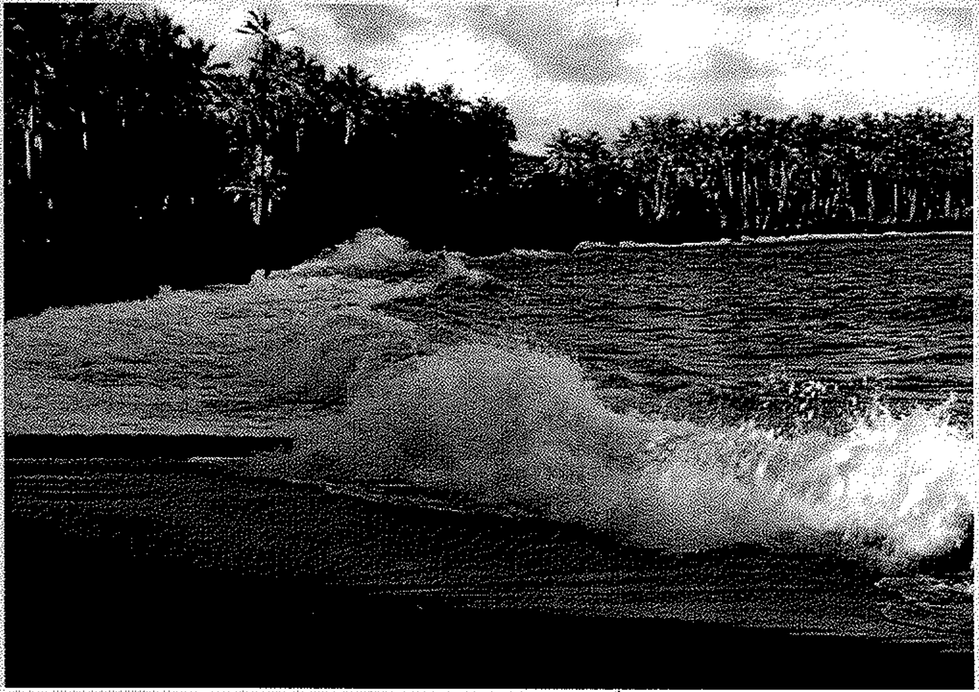
on moderately steep beaches that decelerate the wave quickly, so the top of the wave literally flies ahead of the bottom. *Spilling breakers* occur on gently sloping beaches. The top of the wave tumbles and slides down the front of the wave as it decelerates slowly. *Surging breakers* occur on very steep beaches that are almost like walls rising out of deep water. Since there's little or no bottom contact, the waves don't slow down, but surge virtually unbroken. Surging waves can be very destructive because they don't lose much energy.

Different types of waves require different techniques if you're diving through surf, and the characteristics of each have advantages and disadvantages. Plunging breakers can be difficult because they crash down on you, but the advantage is they usually have a short surf zone that you can move through quickly if you time it right. Surging waves are very strong and can slam you against walls and rocks, yet you can use them to lift you onto shore for your exit. Before diving in unfamiliar surf conditions, get an orientation to the appropriate techniques from your local PADI Dive Center or Resort.

Refraction, Diffraction and Deflection. The previous description of surf is somewhat idealized because it assumes that waves hit the shore squarely. In reality, that rarely happens. *Refraction, diffraction*, and *deflection* affect wave behavior.

As you learned in reading about longshore currents and longshore drift, waves approaching shore from an angle tend to turn until they're parallel with the shore. Drag on the shallower, inshore side of the wave causes this, and is known as wave refraction. When the shoreline is irregular, refraction tends to concentrate wave energy toward headlands because the wave crest nearest to the headland slows first, turning the wave toward it.

Wave diffraction occurs when waves pass an obstacle, such as a jetty. Energy shifts within the wave, allowing a new wave pattern to form past the obstacle or through an opening. Diffraction is what allows very heavy



Surging breaker.

seas to rock an otherwise well protected harbor. Waves diffracted after passing through island channels can alter swell patterns well off shore.

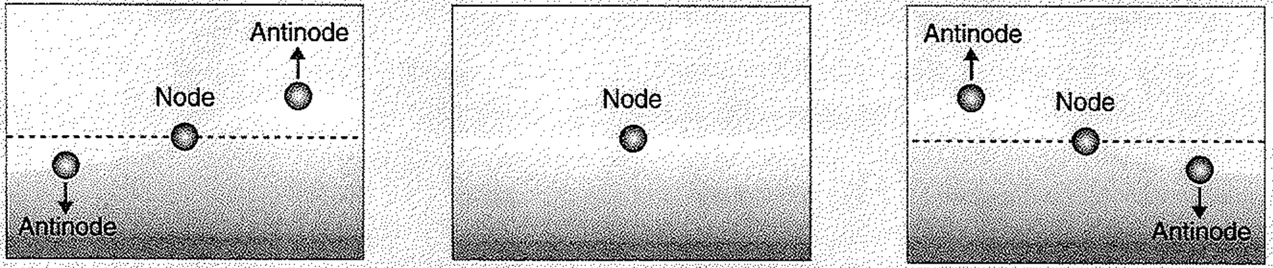
Reflection occurs when waves hit an abrupt obstacle that is nearly perpendicular in the water, such as a seawall. The wave retains most of its energy and bounces back toward the open water. Reflected wave energy can bounce around the inside of an enclosed area, creating complex wave patterns. A good example is the pattern that you get with a single splash in a still swimming pool. At first a single wave set travels from the splash, but when it reaches a wall, it reflects in a new direction as a new set of waves. Meanwhile, the other side of the wave reaches another wall, doing the same thing. Soon, there's no discernible pattern as the reflected waves interact and continue to reflect.

Reflection can also cause a *standing wave*. A standing wave is a vertical oscillation in which water rocks back and forth, rising and falling at the ends but relatively motionless near the center, like coffee sloshing back and forth after you bump the cup. A standing wave isn't orbital, but has a trough and crest that alternate in a single position. The point in the wave that is stationary is called its *node*; the *antinodes* occur where there's maximum vertical change.

DESTRUCTIVE WAVES

On the open sea, sometimes even very large waves can seem harmless. A ship rides up and over them. When they reach shallow water and unleash their energy, however, their power becomes visible. Waves driven by storm winds can be dangerous to coastal areas. There are three distinct types of wave noted for their destructive power: storm surge, seiche, and tsunami.

Storm surge is a destructive wave that forms when high winds push water against the shore, where it piles up. The shallower the water, and the further it extends offshore,



A standing wave is a vertical oscillation in which water rocks back and forth, rising and falling at the ends but remaining relatively motionless near the center. The point in the wave that is stationary is called its node; the antinodes occur where there's maximum vertical change.

the greater the surge. This is why the US Gulf Coast has the biggest storm surges, which can exceed 9 metres/30 feet for a Category 5 hurricane.

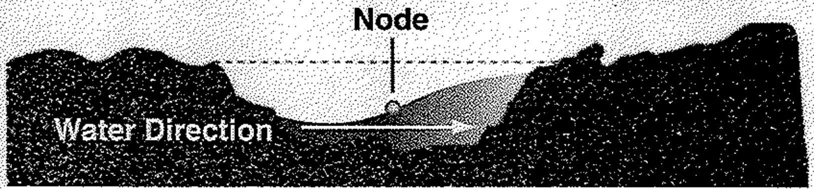
When the storm moves ashore, the storm surge builds on top of the tide. The damage to low-lying coastal areas can be tremendous when storm surge and an extremely high tide coincide. Although hurricane winds cause the most structural damage, about 90 percent of deaths in a hurricane result from the storm surge. Storm surge is not a progressive wave and exists only in a cyclonic storm.

Seiche is a form of standing wave that can be destructive. Seiches, which form in large bays and lakes as a wave that rocks back and forth, can result from a strong wind that pushes the water level up on one side of a basin. When the wind abates, the water rocks back and forth at a frequency determined by the basin size and depth.

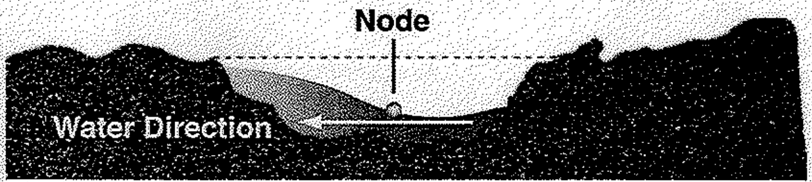
Historic NSW Collection/NOAA

Storm surge. 3.3 metres/16 feet of storm surge struck the Florida panhandle in September 1975.

Lake Geneva, Switzerland, is known for seiches and is, in fact, where scientists first described the phenomenon. All the US Great Lakes have seiches regularly. When combined with storm waves, seiches sometimes cause waterfront property damage.



Enclosed Bay



Enclosed Bay

A seiche is the sloshing of a closed body of water. The back-and-forth water movement can be caused by a local earthquake or when a strong wind blowing in one direction suddenly stops.

A *tsunami* results from sudden water displacement caused by a landslide, an iceberg falling into the sea from a glacier, a volcanic eruption, or, most commonly, an earthquake. Tsunamis get their name from the Japanese word for *harbor wave*, thanks to their particular destructiveness in harbors and bays. You may have also heard them called tidal waves, though this is a misnomer because they're not caused by the tides or directly related to the tides in any way. Initially it may seem strange, but all tsunamis are shallow-water waves in the same way that the tidal bulge is a shallow-water wave. The typical tsunami has a wavelength of about 200 kilometres/120 miles, yet the deepest point in the oceans (Mariana Trench) is about 11 kilometres/6.8 miles deep. There's no ocean deep enough to make a tsunami behave as a deepwater wave. Although they are waves, when they hit they usually seem to behave more like a flood rushing ashore.

Tsunamis are fast-moving waves that can travel thousands of kilometres/miles. They're not much of an issue in the open sea. They have very long wavelengths and are nearly imperceptible as they travel. Vessels may rise and fall about one metre/three feet when a tsunami passes, but they do so

Clocking a Tsunami

Care to outswim a tsunami? Just how fast are tsunamis, anyway? If you know the depth, you can figure it out for yourself. The velocity of a shallow-water wave is determined by this equation:

$$V = \sqrt{gd}$$

where:

V = velocity

g = the acceleration of gravity (9.8 meters per second squared)

and

d = the water depth.

That is, velocity = square root of gravity times depth.

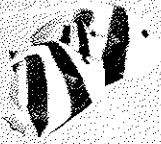
Suppose a tsunami originates in water that is 4000 meters deep.

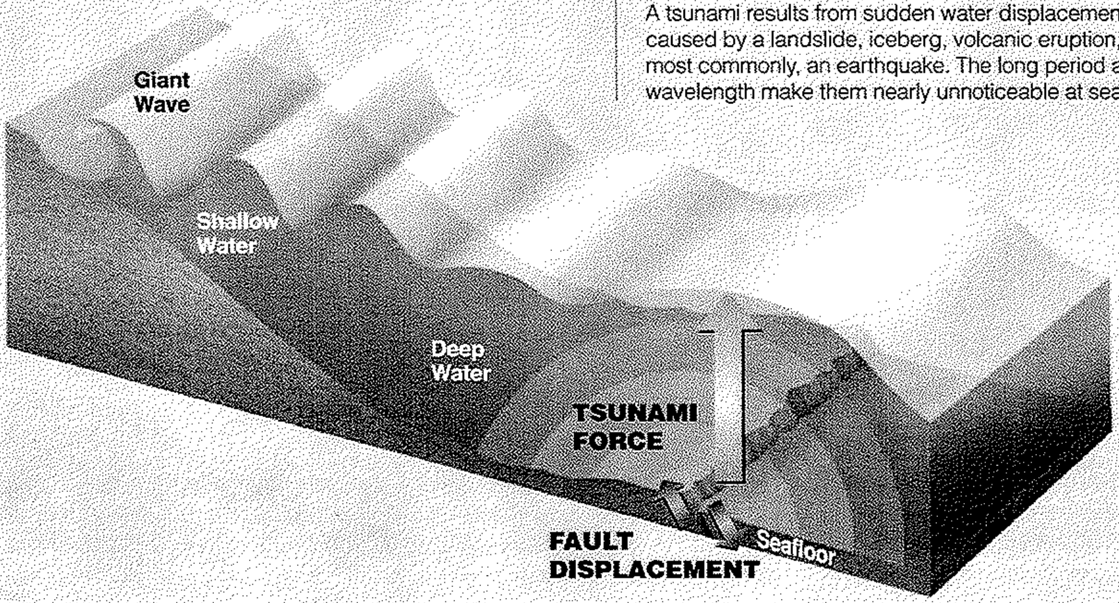
$$V = \sqrt{(9.8\ \text{m/s}^2) \times (4000\text{m})}$$

$$V = \sqrt{39{,}200\ \text{m}^2/\text{sec}^2}$$

$$V = 198\ \text{m/sec}$$

Therefore, the velocity of the tsunami would be 198 meters per second. That works out to 712.8 kilometres/442.9 miles per hour until the wave hits shallower water.





A tsunami results from sudden water displacement caused by a landslide, iceberg, volcanic eruption, or, most commonly, an earthquake. The long period and wavelength make them nearly unnoticeable at sea.

very gradually. Japanese folklore relates an incident in which fishermen at sea all day sailed home to find their village wiped out by a tsunami. The fishermen were unaware it had passed under them.

When a tsunami reaches shore, it becomes much higher. The wave surges ashore, breaks and hurls tremendous water mass and energy onto land. If the trough precedes the crest to shore, the wave water recedes as if a massive low tide were in progress. The building period can take several minutes and has accounted for some fatalities. Curious beachgoers, unaware of the danger, have wandered out onto the drained seabed caused by the preceding trough, only to be drowned by the wave a few minutes later. History records a tsunami surging up a hillside 530 metres/1740 feet high in Lituya Bay, Alaska, USA, in 1958.

TIDES

Tides are waves responsible for the, usually, twice-daily rise and fall of the sea surface that alternately covers and exposes marine life along the shore. They play an important role in determining when certain locations will experience strong currents, changing depth and changing visibility. Therefore tides affect dive conditions – sometimes improving them, and sometimes worsening them. Tides also affect aquatic life, principally in marine environments where tidal currents affect the distribution of planktonic organisms. Tidal

Shahram Saber

Devastation caused by the 2004 tsunami in Southeast Asia.

The 2004 Tsunami

On 26 December 2004, more than 140,000 people were killed across southern Asia in massive sea surges triggered by the strongest earthquake in the world in 40 years. Hundreds of thousands more people were left homeless, their lives all but wiped out by the disaster.

The magnitude 9.0 undersea earthquake struck off the western coast of Sumatra, Indonesia at 07:58:50 local time. It was the strongest in the world since the 9.2-magnitude earthquake which struck Alaska, USA in 1964, and the fourth largest since 1900. The largest recorded earthquake was the Great Chilean Earthquake of 1960, at magnitude 9.5.

Deaths in this quake were caused by resulting tsunamis, which in Thailand were up to 10 metres/33 feet, and struck within three hours of the initial event. Multiple tsunamis struck and ravaged coastal regions of nine countries in the Indian Ocean, devastating regions including the Indonesian province of Aceh, the coast of Sri Lanka, coastal areas of the Indian state of Tamil Nadu, the resort island of Phuket, Thailand, and even as far away as Somalia, 4100 kilometres/2500 miles west of the epicenter.

About 80 percent of all tsunamis occur in the Pacific and many cities around the ocean – mostly in Japan, but also in Hawaii – have warning systems and evacuation procedures for serious tsunamis. One of the best ways to predict tsunamis is to monitor earthquakes, which set off most of the waves. Seismograph networks, wave gauges (such as those operated by International Tsunami Warning System) and satellite measurements of sea level changes can help warn of tsunamis.

movement results from the gravitational interaction of the earth, moon and sun. As a general guideline, the best diving conditions occur at high tide.

The cyclical nature of the orbits and planetary motion of the earth, moon and sun make the tides predictable. Tide duration, number and range depend on the relative position of these three bodies and the local topographical features. By using this information, people can generate accurate tide and current tables to predict both the times and heights of tides anywhere in the world. Aquatic organisms – particularly those living in the intertidal zone – simply rely on biological clocks to regulate their activity to the tides. Before a dive, check local tide tables and become familiar with how tides affect local conditions and aquatic life.

The Causes of Tides. Tides result from the gravitational pull of the moon and, to a lesser degree, the sun. They pull ocean water into a huge wave with a wavelength the size of an ocean basin. In principle, the sun and moon create two bulges on opposite sides of the earth. The relative positions of the sun and moon change slowly, so the bulge rotates around the earth. As a coastline rotates into the bulge, the tide rises. As it rotates out, the tide falls.

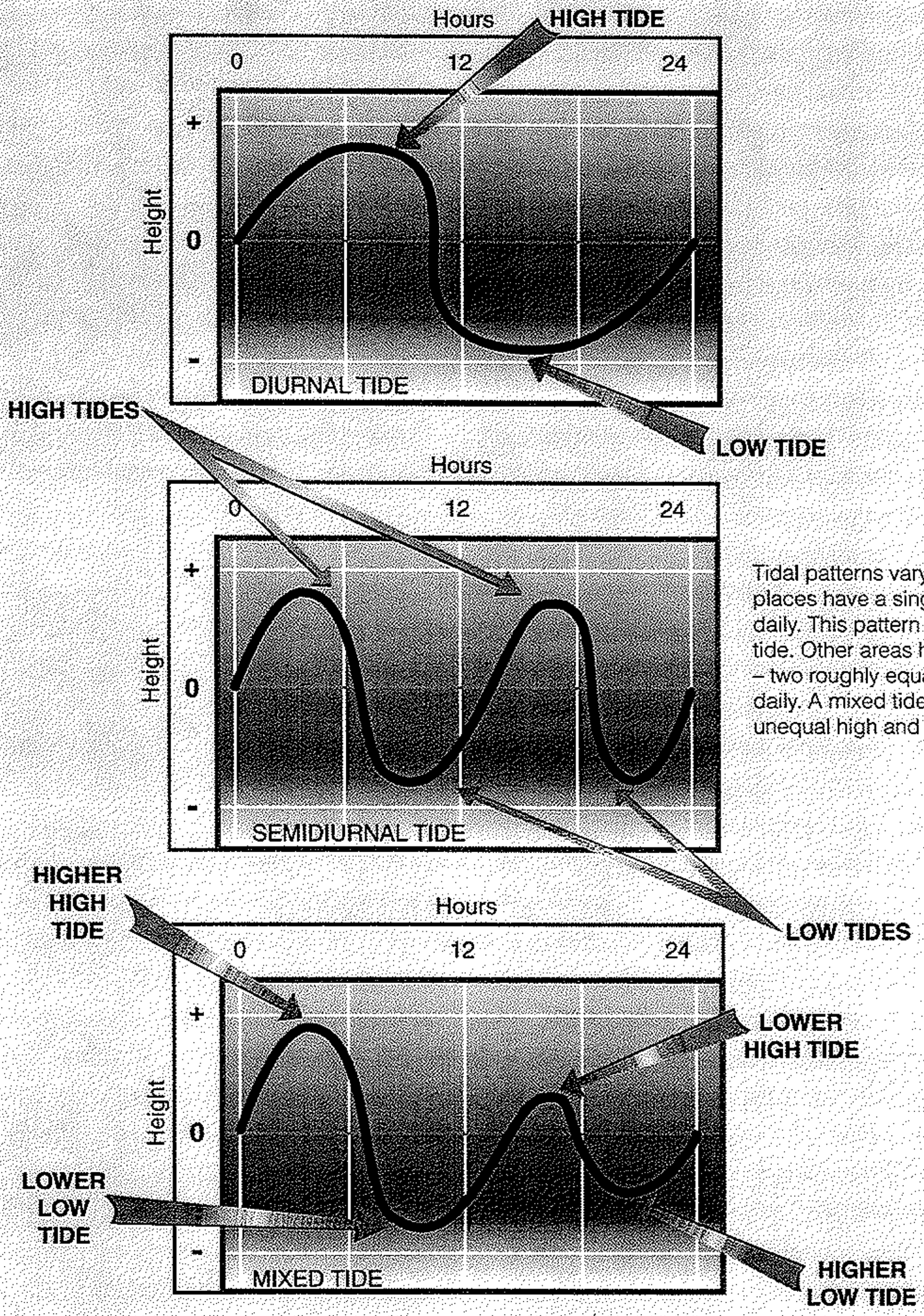
Isaac Newton proposed this simplistic explanation of the tides. It is called the *equilibrium theory*, which assumes that the earth is perfectly uniform, that water is very, very deep, and that there are no landmasses. The problem with the equilibrium theory is that the earth isn't perfectly uniform, the water isn't always very deep and there are many landmasses. This is why Newton's theory is too simple to explain the actual tides on the earth. Some places have two tides in a day, others have one. In some places the tides are very extreme, in others they're not. Because of landmasses and varying depths, the tides don't move like an unobstructed wave in the open sea. They are waves that are forced through and around obstacles. Understanding this requires a more complex model.

Pierre-Simon Laplace modified Newton's model to account for tidal variations. His model, called the *dynamic theory*, shows that there aren't only two tidal bulges; rather, there are several tidal bulges. This is because, in addition to lunar and solar gravity, the imperfect sphere of the earth, the season, the time of the month, the shape of the ocean basin, and the Coriolis effect all influence the tides. Tides rotate around more than a dozen *amphidromic points*. These are points where the water doesn't rise and fall with the tides. The tides occur in a pinwheel-shaped, standing-wave pattern. There is no vertical tidal movement at an amphidromic point, but away from that point there may be magnified tidal motion as the tides change throughout the day.

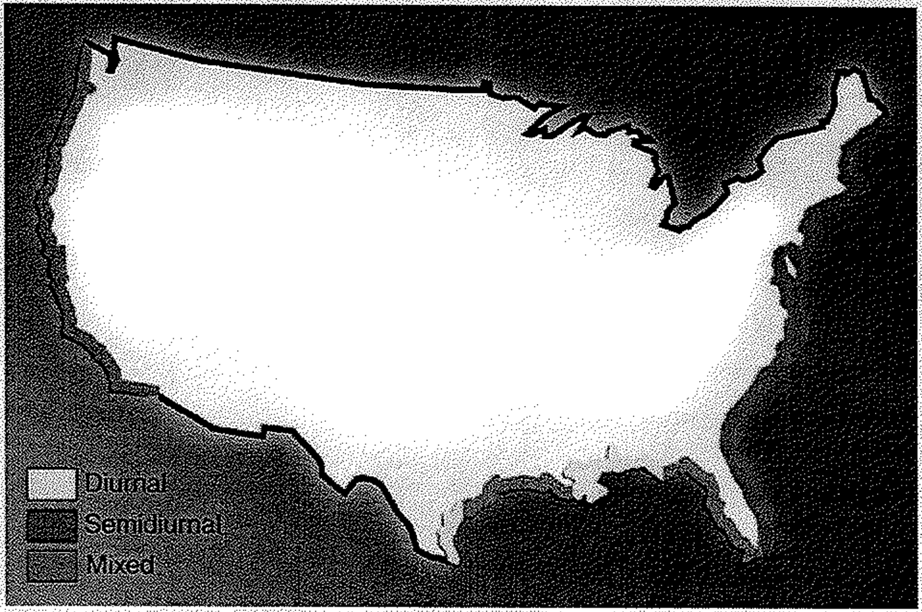
Tidal Patterns and Currents. Because there are multiple tidal bulges and other influences, tidal patterns vary with location. Some places have a single high and low tide daily. This pattern is called a *diurnal tide. Semidiurnal tides* means having two roughly equal high and low tides daily, as predicted by Newton's model. *Mixed tides* means a pattern that consists of two unequal high and low tides daily. Different areas have different tidal patterns depending upon the location of amphidromic points. For this reason, a very long stretch of coastline can have more than one tidal pattern.

The shape and depth of the ocean basins affect tidal patterns. The range – the difference between high and low tides – depends mostly on the basin shape and size. Large, wide basins tend to have a smaller tidal range than narrow, shallow basins.

The daily tides create a current that flows into and out of bays, rivers, harbors and other restricted spaces. The inflow is called a *flood current* and the outflow is called a *slack current.* The midpoint between high and low tides creates slack tide, when there is little water moving. These tidal variations are important to people who work on and around the sea. Large ships may only be able to enter or exit a harbor during high tide to ensure sufficient water depth for travel. Sailing ships often use the slack current to take advantage of the flow carrying them seaward.



Tidal patterns vary with location. Some places have a single high and low tide daily. This pattern is called a diurnal tide. Other areas have semidiurnal tides – two roughly equal high and low tides daily. A mixed tide is where there are two unequal high and low tides daily.



Tidal patterns of the United States demonstrate how even relatively close areas (globally speaking) can have different tides. On the west coast and in parts of the Gulf of Mexico, mixed tides predominate. Other parts along the Gulf of Mexico have diurnal tides. The east coast of the United States is dominated by semidiurnal tides.

In some instances, a *tidal bore* can form. This is when the incoming tide produces a wave that flows into a river, bay or other relatively narrow area. This is a true tidal wave (i.e., a wave caused by a tide) and can be several metres/feet high. On the Amazon River in South America and the Severn River in England, surfers can take long rides on the tidal bore.

Spring Tides and Neap Tides. The influence of the moon on the tides is about twice the influence of the sun. The sun has much more gravity but affects the tides less than the moon because it's so much farther away. Solar and lunar gravity affect the tides differently, depending on the positions of the sun and moon relative to the earth.

When the sun, the moon, and the earth are aligned, their gravity works together, raising the height of the tidal water bulges. You can tell when this happens by the phases of the moon. When there's a new moon (no moon visible), both the sun and the moon are aligned on the same side of earth, and during a full moon the sun and moon are aligned on opposite sides of earth. Both positions create the highest and lowest tides, called *spring tides.*

When the moon is in a quarter phase, the lines from it and the sun to the earth form a right angle. The sun's gravitation pulls to the side of the moon's tidal bulge. This tends to raise the low tide and lower the high tide. These weaker tides are called *neap tides.*