

OCEANS

The ocean is the interconnected body of salt water that covers 71 percent of the surface of our planet. Even the 29 percent of the Earth's surface that consists of dry land owes some of its most basic characteristics to the ocean, largely because of its influence on global climates. The ocean moderates temperatures around the world, and most of the precipitation that falls on land is derived from water vapour that evaporated from the sea.

The ocean is commonly considered to comprise both the beginning and the end of the global hydrologic cycle. It is sometimes referred to as the 'hydrologic sink' because some 96.7 percent of all water at or near the surface of the Earth is located in the ocean at any one time, and because millennia may pass between the time a given water molecule enters the ocean as precipitation or runoff and the time it evaporates to begin another journey through the cycle.

Origin, Distribution and Extent

Ocean water originated in the same way as did the surface and sub-surface water of the land. It was released from its original solution in rock deep within the Earth as the rock moved surfaceward as magma; subsequently, it entered the atmosphere in the form of water vapour during volcanic eruptions. Cooling and condensation of the water vapour caused it to precipitate to the surface, where it accumulated in the enclosed basins that hold the ocean water.

The present geographical distribution of the ocean is closely related to the distribution of the types of rocks composing the Earth's crust. The entire crust 'floats' on the semisolid material of the underlying mantle. Much of the crust consists of dense basaltic rock that floats at a relatively low level, producing the ocean basins. The less-dense granitic rock from which the continents are constructed is sufficiently buoyant and high standing to remain above the ocean level. Put another way, the ocean has simply covered the lowest 71 percent of the Earth's lithospheric surface. This includes approximately 60.6 percent of the northern hemisphere and 81.0 percent of the southern hemisphere.

Several major subdivisions of the ocean exist; they also are termed oceans. The mean depths of the water in the various oceans are rather consistent with the exception of the comparatively shallow Arctic Ocean. Depths range from 0 along the coasts to a maximum of 11,033 meters (36,198 ft) in the Marianas Trench in the western Pacific. The enlisted mean oceanic depth of 3,865 meters (12,680 ft) is almost five times the average elevation of the world's land areas, which is estimated at 841 meters (2,760 ft). The vertical dimensions of the ocean therefore exceed those of the continents even more than do its horizontal dimensions.

Physical and Chemical Characteristics

Ocean water displays substantial spatial variation in a number of physical and chemical characteristics. Among the most important are chemical constituency, temperature and the presence or absence of ice.

Constituency

Seawater averages about 96.5% water and 3.5% percent dissolved solids by weight. Nearly every known substance is soluble to some extent in water, and about two-thirds of the 92 naturally occurring chemical elements have been found in

seawater. The great majority of these solids, by weight, are ions of salts. More than 99 percent consist of the six elements – chlorine, sodium, magnesium, sulphur (as sulphate), calcium and potassium. Chlorine and sodium are the two dominant elements by far and, upon evaporation of sufficient water, will combine to form common table salt, or sodium chloride (NaCl).

The origin of the salinity of the ocean is similar to that of saline lakes. Over several billion years, runoff from the land has carried to the sea tremendous quantities of dissolved salts. Because there is no natural mechanism for removing these salts until saturation occurs (and the oceans are still well below the salt saturation level), salinity continues to gradually increase. The quantity of salt in the ocean is now so great that, if removed, it would exceed in volume the portion of the continent of Africa that is above sea level.

Near-surface salinity levels vary somewhat over the open ocean because of losses of water to evaporation and gains of fresh water from rivers or precipitation. In general, salinity levels are highest in the subtropics, where large net evaporative water losses concentrate the salts. Large variations in salinity may occur only in restricted seas where communication with the major ocean basins is limited. For example, the Black Sea, which receives large quantities of fresh water from the Danube and other rivers, has a salinity of only 1.6 percent. The shallow Baltic Sea sometimes has salinities as low as 0.1 percent in the spring snowmelt season. On the other hand, the eastern Mediterranean and Red Seas are located in arid climates and have summer salinity levels of 4 percent or more.

Temperature

The temperature of the ocean surface varies considerably in different parts of the world. Away from the continental margins, the temperature distribution pattern generally is similar to that of the atmosphere. Extensive areas of tropical ocean water have surface temperatures between 26.5° C and 29.5° (80 and 85° F), and values gradually fall with increasing latitude to readings near or slightly below 0° C (32° F) in the subpolar and polar regions. The mean temperature of the ocean surface water as a whole is about 21° C.

A basic difference in the thermal behaviour of the continents and ocean is that the latter experiences smaller temperature variations, especially on a seasonal and daily basis. Annual temperature variations of the open ocean waters reach a maximum of 8 to 10° C (15 to 18° F) in the middle latitudes of the northern hemisphere and 5 to 6° C (9 to 10° F) in the middle latitudes of the more highly maritime southern hemisphere. Variations of at most 1.5 to 2° C (3 to 4° F) are typical of the tropics. Seasonal temperature variations decrease rapidly with depth and, in most places, do not occur at all at depths greater than 180 meters (600 ft). Daily water temperatures on the open ocean vary less than 0.5° C (1° F).

Despite the transparency of the ocean, most insolation is absorbed in the top 1.5 meters (5 ft) of water. As a consequence, outside the polar regions, water temperatures, decline everywhere with depth. The warm surface water is lighter and more buoyant than the underlying water and remains at the surface. Conversely, cold water produced in the high latitudes becomes dense enough to sink and spread outward at depth. As a result, all ocean water at depths greater than 3,000 meters (10,000 ft) is derived from the polar regions and has a constant temperature of approximately 2° C (35° F). The aggregate mean temperature of all water in the ocean is about 4° C (39° F).

It has recently been discovered that extensive portions of the ocean surface waters can vary in temperature by several degrees Celsius over periods of one or more years. Because of the constant exchange of heat, moisture, and momentum between the ocean and the atmosphere, these thermal variations can have a profound influence on weather conditions both over the oceans and on the adjacent continents. For example, during the early 1970s, water temperatures in the central Pacific became warmer than normal. This warming apparently caused the jet stream to ridge northward over the area, while a trough developed over the western United States, bringing unusually cool and wet weather to the West Coast. This pattern, in turn, apparently induced the formation of a second ridge over eastern North America, causing the East Coast to experience a string of unusually mild, dry winters. In 1982 and 1983, a large-scale warming of the eastern Pacific took place. It was caused by a temporary reversal in the flow pattern of ocean currents in the tropical Pacific – a phenomenon named **El Nino**. Weather conditions were affected on a global scale.

Oceanic Ice

Although more the world's ice is located on the continents, the oceans of the higher latitudes contain both sheet-like masses of sea ice produced by the freezing of seawater and blocks of glacial ice derived from the land. **Sea ice** is extensively distributed in the oceans of the high latitudes, and covers most of the Arctic Ocean, parts of the extreme north-western Atlantic, and much of the water around Antarctica. The extent and thickness of the sea ice vary considerably between summer and winter, but most is less than 3.5 meters (11 ft) thick.

Icebergs are masses of freshwater ice produced by the breakup of glaciers as they enter the sea. Unlike sea ice, glacial ice is derived from the compaction of snowfall on land. Icebergs differ considerably in appearance from sea ice because they do not form continuous thin sheets but instead commonly take the form of individual rugged island-like masses. Sizes vary greatly, but large icebergs may be more than 100 meters (300 ft.) high and have above-water lengths exceeding 1.6 kilometres (91 mi). Between 80 and 85 percent of an iceberg (depending on the amount of entrapped air) is hidden below the water line, so that the visible portion is indeed 'just the tip of the iceberg'.

The chief problem posed by icebergs is their danger to shipping. In the northern hemisphere, most icebergs form from glaciers entering Baffin Bay from the west coast of Greenland. They drift south of the Labrador Current to the Grand Banks area southeast of Labrador, where they are picked up by the Gulf Stream, carried eastward, and eventually melt. One of these icebergs was responsible for the sinking of the ocean liner *Titanic* with a loss of 1,517 lives in 1912.

Few icebergs occur in the North Pacific because no major glacial sources exist in that area. Many icebergs, however, form along the coast of Antarctica. Unlike those of the North Atlantic, they are usually tabular in shape because they have broken off the extensive ice shelves located along portions of the coast. These icebergs can be huge. For example, an iceberg 153 kilometres (95 mi) long and 35 kilometres (22 mi) wide broke off the Antarctic ice shelf in October 1987. Such icebergs have been observed as far equatorward as 30° S.

Motions of the Ocean Waters

The ocean is never completely still. It is influenced by a variety of forces originating on above, and below the surface that keep it in a state of constant motion.

The water movements are commonly divided into the three categories of currents, waves and tides.

Currents

Ocean **currents** are continuous movement of water streams of similar temperature and density. These currents aid in the transport of excess energy from the tropics to the higher latitudes and have a profound influence on global climates.

The most important ocean currents are those at and near the surface because they interact with the atmosphere and coast and affect shipping. The energy that sets these currents in motion is the frictional drag of the wind on the water surface. As a result, both the speed and the direction of the surface currents are determined largely by the global wind belts, and the planetary patterns of winds and ocean currents are similar in several respects.

The vast inertia of the ocean water causes the ocean currents to be more consistent in their position, speed, and direction of flow than are the wind currents. Satellite imagery and surface observations have revealed, however, that the ocean currents develop constantly changing patterns of swirls and eddies along their routes, and that extensive eddy fields generated by the flow of the currents involve much of the ocean surface water in slow swirling motions. The ocean currents flow at a much slower average speed than the wind; flow rates average only 1.5 to 3.0 kilometres per hour (1 to 2 mph) and do not exceed 9 kilometres per hour (5.5 mph).

Two factors other than the wind also play important roles in determining the overall pattern of ocean current flow. One is the Coriolis Effect produced by the Earth's rotation, which deflects currents to the right of the prevailing wind flow in the northern hemisphere and to the left in the southern hemisphere. The net influence of the Coriolis Effect is to produce an average 45° deflection of the surface currents with respect to the winds.

The other major influence on the global ocean current pattern is the configuration of the ocean basins and the continental margins. Unlike the wind, which is free to pass over land and water alike, the ocean currents are, of course, restricted to the ocean basins. As they approach land, they are redirected and often split into complex patterns that may bear little relation to the prevailing wind pattern.

If the three largest oceans are divided by the equator, a total of five extensive ocean basins are produced: the North and South Pacific, the North and South Atlantic, and the South Indian Oceans. (The North Indian Ocean is too small in size to be considered an additional member). The currents in each basin follow a basic pattern that is essentially similar; it consists of a giant elliptical loop, called a gyre, elongated in an east-west direction. The oceanic gyres are centred at roughly 30° N and S. They correspond closely in position to the oceanic centres of the subtropical highs and are, in fact, produced largely by the wind circulations around these highs. Like the wind, the currents flow clockwise around their centres in the northern hemisphere and counter clockwise in the southern hemisphere.

Currents largely unrelated to those at the surface exist at depth in the oceans. Unlike surface currents, the oceanic **deep currents** are produced by differences in water density resulting from variations in temperature and salinity. Deep currents have significant vertical as well as horizontal components of motion. A slow circulation occurs between the surface water and the deep water. Surface water descends to great depths in zones of convergence, mostly located where cold, dense water from the high latitudes encounters and plunges beneath warmer water from the middle latitudes. Extensive convergence occurs in the waters around Antarctica and in

the North Atlantic south of Greenland. These zones of convergence are the sources of the cold deep water that exists throughout the ocean. Deep water eventually returns to the surface in zones of **upwelling**. Most of these zones are situated near the west coasts of continents in subtropics, where equatorward-flowing water is redirected westward by the trade winds. The seaward push of this water causes cold water from great depths to well up to replace it.

A period of several centuries may be required for one complete cycle of convergence, descent, and upwelling. This period is estimated at about 700 years for water of the Atlantic and 1,500 years for that of the Pacific. Slow as it is, this vast vertical circulation system is crucial to sea life. The descent of surface water in areas of convergence carries dissolved carbon dioxide and oxygen needed by marine plant and animal life into the depths. Conversely, the rise of bottom water in zones of upwelling transports nutrients from the sea floor to the surface. As a result, zones of upwelling are the sites of some of the world's most productive fishing grounds. Water in the vast mid-ocean basins is largely cut off from this circulation. As a consequence, it is low in dissolved gases and nutrients and nearly devoid of life.

Waves

Waves are the most familiar of the ocean movements and have the greatest influence on the characteristics of the coastline. Like currents, they are generated primarily by the wind. Unlike currents, though, waves do not produce a significant linear transport of water, although they are efficient transporters of energy over great distances.

Waves are produced by the frictional drag of the wind blowing over the water surface. Once started, the size and energy of waves is increased by the push of the wind against their sides. Three factors determine wave sizes: the wind speed, the **fetch** (the distance over which the wind blows) and the length of time the wind has been blowing from the same approximate direction. An increase in any of these factors increases wave dimensions. The largest wind-generated waves ever reliably reported were 17 metres (55 ft) high. One combination of conditions that would produce waves of this size is a 110 kilometer per hour (70 mph) wind blowing for 24 hours over a fetch exceeding 800 kilometers (550 mi). The largest storm waves are capable of damaging or sinking even large ships and of producing tremendous erosional and structural damage along coasts.

The waves that reach our coastlines at any given time are generated only in certain restricted areas, usually located within storms. They are able to travel hundreds or even thousands of kilometres before eventually reaching distant shores. Large waves along the California coast, for example, are often produced by storms near Alaska. On occasion, waves reaching Hawaii are generated in storms off the coast of Antarctica.

Waves lose little energy as they travel through deep water, but this situation begins to change as they approach the shore and move into shallow water. When the water depth decreases to less than half the wave length, the wave starts to 'feel bottom' as its forward progress begins to be slowed by friction. The restraining influence and upward push of the bottom cause the wave to rise gradually and tilt forward. When the water depth has been reduced to about 1.3 times the wave height, the upper portion of the wave pitches forward and breaks. (The process is much like that of a person who falls forward because he or she has been tripped). The water now becomes foam-filled surf, which for the first time experiences significant net horizontal motion as its forward momentum causes it to rush up the beach as **swash**

and then, its energy spent, to return as **backwash**. During this process, the energy imparted to the wave days earlier in a distant storm finally is expended on the coastline.

Tides

The ocean **tides** are the rhythmic rise and fall of the ocean produced by the gravitational influence of the Moon and Sun. Unlike waves and surface currents, the tides affect the ocean throughout its entire vertical extent. Gravity-induced tides are not restricted solely to the ocean. They also occur in large lakes, on the continents (with displacements of up to 30 centimeters or 12 inches), and in the atmosphere (with displacements of many kilometres). Their practical significance with respect to human activities, however, is greatest by far in the ocean. The ebb and flow of the tides has been observed, pondered, and put to practical use by seafarers for thousands of years. Only in recent times, however, have sufficiently detailed records been compiled in most areas to allow for precise tidal predictions.

Although the Sun is much more massive than the Moon and has a much greater surface gravity, the tidal influence of the Moon is over twice that of the Sun because it is much closer to the Earth. The ocean water on the portion of the Earth directly beneath the Moon is pulled upward, creating a high tide when the Moon is overhead. A second high tide occurs on exactly the opposite side of the Earth because of the rotational inertia of the Earth-Moon system and because that area is farthest from the Moon, making its pull weakest there. Midway between the two areas of high tides are zones of low tides.

The combination of the Earth's axial rotation and the Moon's revolution around the Earth causes the Moon to take 24 hours and 50 minutes to return to its same longitudinal position over the Earth. The pattern of high and low tides rotates with the Moon's changing position, so that most places experience two high tides and two low tides during this period. A time span of 6 hours and 12 minutes therefore normally elapses between subsequent high and low tides.

Although the basic pattern of semi-daily high and low tides are relatively simple, a number of additional influences combine to make the world pattern of oceanic tides exceedingly complex and difficult to predict. One of the most important is the gravitational influence of the Sun. Like the Moon, the Sun acts to produce a pair of high tides in those areas facing directly toward and away from it, with an intervening pair of low tides. The tides actually experienced at any one place therefore result from the combined influence of the Moon and Sun. When these two bodies are aligned either on the same side of the Earth (at the time of the new Moon), or on opposite sides (at the time of the full Moon), their gravitational effects work in concert, and tidal ranges are largest. This produces the so-called **spring tides**, whose occurrences are actually unrelated to the season of the year. When the Sun and Moon are situated at right angles with respect to the Earth (at the times of the half Moon), their gravitational influences are opposed to each other, and tidal ranges are smallest. These are called **neap tides**.

Probably the most important and certainly the most complex of the tidal influences is the geographic pattern of the ocean basins and coastal margins. Their irregular shapes cause the tides to be redirected or reflected in countless ways and often to be augmented, diminished, or even cancelled altogether in some places. Highly uneven coastline frequently experience tides that vary greatly both in range and in time of occurrence over small distances. In broad water bodies, including the

major ocean basins, the tides display a circular pattern, with high and low tides rotating around one or more nodal points or lines that experience no tides at all.

Tidal ranges of 1 or 2 meters (3 to 6 ft) are most common for the world as a whole. The highest tides occur in funnel-shaped bays or estuaries, where the tidal influence is focused by the converging shorelines. Nova Scotia's Bay of Fundy has the highest tides of all, with one site experiencing a mean spring tidal range of 14.5 meters (47.5 ft) and an extreme range of 16.5 meters (53.5 ft).

Tides in restricted bodies of water may be so concentrated that strong **tidal currents** are formed. These consist of currents that flow landward during the period of the rising tide and seaward during the period of the falling tide. If a current is forced to advance upstream against a strong downstream flow of river water, its progress is slowed and water may be piled up at its forefront to produce a tidal bore. In the lower Amazon, such a **tidal bore** advances upriver as a wave for a distance of 480 kilometers (300 mi). In places it forms a wall of water 5 meters (16 ft) high that travels at a rate of 22 kilometers per hour (14 mph) and produces a roar that can be heard for great distances.

The net result of the combination of tidal influences is that most localities experience alternating higher and lower high and low tides. Even a thorough understanding of all the tidal influences does not make it possible to forecast the height of the tides precisely. This is because ocean levels are also strongly influenced by constantly changing patterns of wind direction, fetch, and speed and, to a lesser extent, by variations in air pressure.