8 OCEANS AND COASTAL ENVIRONMENTS

Most people love shorelines. They love panoramic ocean views, they love sandy beaches on crystal-clear lakes, they love to swim and surf and go out in boats, and they love watching giant waves crash onto rocky shores. While an understanding of coastal processes isn't necessary for our enjoyment of coastal regions, it can make our time there much more interesting. But an understanding of coastal processes is critical to people who live near a coast, or those who like to spend a lot of time there, because in order to be safe and avoid damage to infrastructure, we need to know how coastal processes work. We also need to understand the processes in order to avoid some of the possible consequences of changes that we might like to make in coastal areas.

8.1 Significance of Oceans

The oceans makeup 70% of the planet and contain 97% of all the water on Earth. Watch the video below that shows what the Earth would look like if all the ocean water were gone.

It also makes up most of the water stores the majority of the planet's moisture, terrestrial energy, and heat from the Sun. This energy is transferred between the equator and the two poles by larger surface currents by winds and deep ocean currents driven by ocean density differences. It also supplies the moisture and energy for storm systems and, ultimately, global climates. (1) It is important to study the oceans, and their exploration is an exciting and ongoing process.

Phytoplankton, microscopic plants, and animals in the oceans provide the foundation of the global food web of species. They contain chlorophyll and require sunlight in order to grow, and provide food for a wide range of sea creatures. The earth's oceans are so vital for life that over 40 percent of the world's population lives near coastal areas. (1)

Moderate Climates

As terrestrial creatures, humans think of the importance of the planet's land surfaces, yet Earth is a planet consisting of 70 percent water. From space, the dominance of water is clear because most of it is stored in Earth's oceans. Earth would not be the same planet without its oceans. The oceans, along with the atmosphere, keep Earth's surface temperatures relatively constant worldwide. Some places on Earth reach as cold as -7 degrees Celsius, while other places reach as hot as 55 degrees Celsius. On other planets like Mercury, temperatures range from -180 degrees Celsius to 430 degrees Celsius. (2)

The oceans, along with the atmosphere, distribute heat around the planet. The oceans absorb heat near the equator and then transport that solar energy to polar regions. The oceans also moderate the climate within a region. At the same latitude, the temperature range is smaller and coastal areas compared to areas farther inland. Along coastal areas, summer temperatures are not as hot, and winter temperatures are not as cold, because water takes a long time to heat up or cool down. (1)

Biologically Rich

The oceans are an essential part of Earth's water cycle. Since they cover so much of the planet, most evaporation comes from the ocean, and most precipitation falls on the oceans.

The oceans are also home to an enormous amount of life. That is, they have tremendous biodiversity. Tiny ocean plants create the base of a food web that supports all sorts of life forms. Marine life makes up most of all biomass on Earth. **Biomass** is the total mass of living organisms in a given area. These organisms supply us with food and even the oxygen created by marine plants. **(1)**

Continental Margins

Recall from the chapter on Plate Tectonics that the ocean floor is not flat. Mid-ocean ridges, deep-sea trenches, and other features all rise sharply above or plunge deeply below the abyssal plains. Earth's tallest mountain is Mauna

Kea volcano, which rises 10,203 m (33,476 ft.) from the Pacific Ocean floor to become one of the volcanic mountains of Hawaii. The deepest canyon is also on the ocean floor, the Challenger Deep in the Marianas Trench, 10,916 m (35,814 ft). The mapping of the ocean floor and coastal margins is called **bathymetry**. The **continental margin** is the transition from the land to the deep sea or, geologically speaking, from continental crust to oceanic crust. More than one-quarter of the ocean basin is the continental margin.(3)

Composition of Ocean Water

The ocean's water is a complex system of organic and inorganic substances. Water is a polar molecule that can dissolve many substances such as salts, sugars, acids, bases, and organic molecules. Saltwater comes come water that moves through rock and soil on the land and picks up ions. This is the flip side of weathering. Salts comprise about 3.5 percent of the mass of ocean water, but the salt content or **salinity** is different in various locations. (1)

In places like estuaries, seawater mixes with freshwater, causing salinity to be much lower than average. Where there is lots of evaporation, but minimal circulation of water, salinity can be much higher. The Dead Sea has 30 percent salinity, nearly nine times the average salinity of ocean water. It is called the Dead Sea because nothing can survive within it because of its salinity. (2)

Layers of the Ocean

In 1960, two scientists in a specially designed submarine called the "Trieste" descended into a submarine trench called the Challenger Deep (10,910 meters). The average depth of the ocean is 3,790 m, a lot shallower than the deep trenches but still an incredible depth for sea creatures to live in. Three significant factors make the deep ocean hard to inhabit: the absence of light, low temperature, and extremely high pressure. The National Weather Service as information on the layers of the ocean. (2)

Vertical Divisions

To better understand regions of the ocean, scientists define the **water column** by depth. They divide the entire ocean into two zones vertically, based on the light level. Large lakes are divided into similar regions. Sunlight only penetrates the sea surface to a depth of about 200 m, creating the **photic zone** (consisting of the Sunlight Zone and Twilight Zone), also known as the epipelagic zone. Organisms that photosynthesize depend on sunlight for food and so are restricted to the photic zone. Since tiny photosynthetic organisms, known as **phytoplankton**, supply nearly all of the energy and nutrients to the rest of the marine food web, most other marine organisms live in or at least visit the photic zone. In the aphotic zone (consisting of the Midnight Zone and the Abyss), there is not enough light for photosynthesis. The **aphotic zone** makes up most of the ocean, but has a small amount of its life, both in the diversity of type and numbers. (3) Figure 8.1.5 shows the vertical divisions of the ocean.

As these zones transition from one to the other, a thermocline forms. A thermocline is the transition layer between the warmer mixed water at the surface and the cooler deep water below. It is relatively easy to tell when you have reached the thermocline in a body of water because there is a sudden change in temperature. In the thermocline, the temperature decreases rapidly from the mixed layer temperature to the much colder deep water temperature. In the ocean, the depth and strength of the thermocline vary from season to season and year to year. It is semi-permanent in the tropics, variable in temperate regions (often deepest during the summer), and shallow to nonexistent in the polar regions, where the water column is cold from the surface to the bottom. (1)

Thermoclines also play a role in meteorological forecasting. For example, hurricane forecasters must consider not just the temperature of the ocean’s skin (the sea surface temperature), but also the depth of warm water above the thermocline. Water vapor evaporated from the ocean is a hurricane’s primary fuel. The depth of the thermocline is the measure of the size of the “fuel tank” and helps to predict the risk of hurricane formation. (1)

Horizontal Divisions

The seabed is also divided into the zones described above, but the ocean itself is separated horizontally by distance from the shore. Nearest to the shore lies the **intertidal zone**, the region between the high and low tidal marks. This hallmark of the intertidal is changed, where water is in constant motions from ocean waves, tides, and currents. The land is sometimes underwater and sometimes is exposed. The **neritic zone** is from low tide mark and slopes gradually down to the edge of the seaward side of the continental shelf. Some sunlight penetrates the seabed here.
The **oceanic zone** is the entire rest of the ocean from the bottom edge of the neritic zone, where sunlight does not reach the bottom. (1)

8.2 Waves and Shoreline Currents

Waves

Waves form on the ocean and lakes because energy from the wind is transferred to the water. The stronger the wind, the longer it blows, and the larger the area of water over which it blows (the fetch), the larger the waves are likely to be.

The essential parameters of a wave are its **wavelength** (the horizontal distance between two crests or two troughs), its **amplitude** (the vertical distance between a **trough** and a **crest**), and its velocity (the speed at which wave crests move across the water). Relatively small waves move up to about 10 km/h and arrive on a shore about once every 3 seconds. Huge waves move about five times faster (over 50 km/h), but because their wavelengths are so much longer, they arrive less often – about once every 14 seconds. (4)

As a wave moves across the water's surface, the water itself mostly moves up and down and only moves a small amount in the direction of wave motion. As this happens, a point on the water surface describes a circle with a diameter equal to the wave amplitude. This motion is also transmitted to the water underneath, and the water is disturbed by a wave to a depth of approximately one-half of the wavelength. (1)

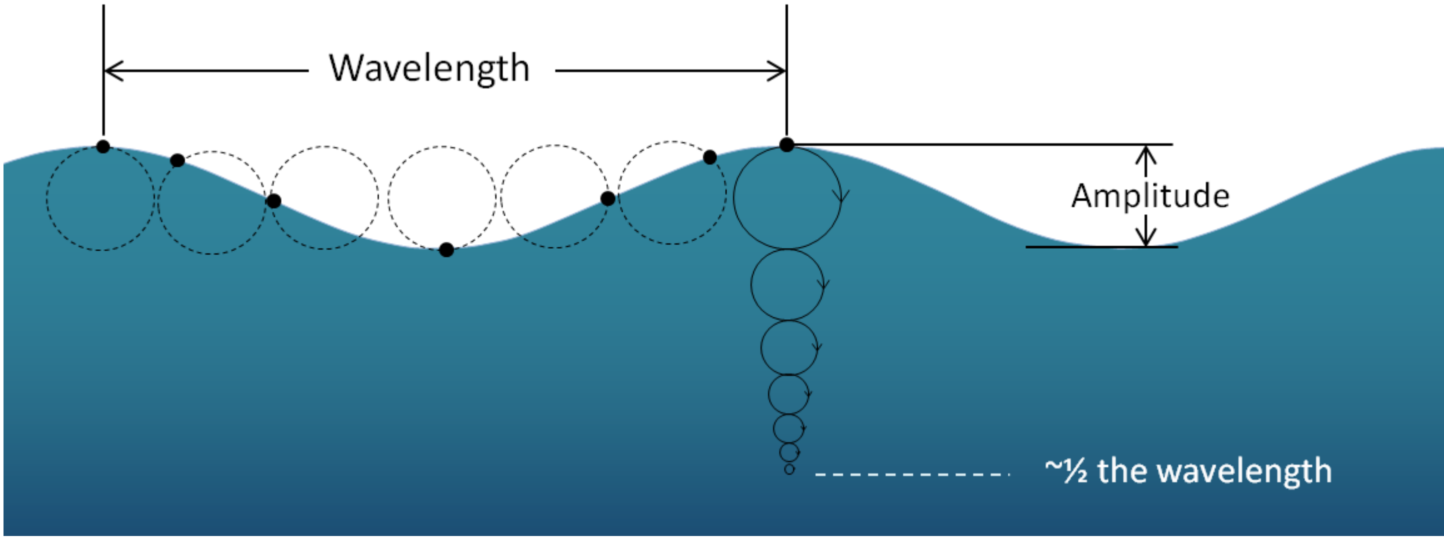


Figure 8.2.1 The orbital motion of a parcel of water (black dot) as a wave moves across the surface. S. Earle, CC-BY

The one-half wavelength depth of disturbance of the water beneath a wave is known as the **wave base**. Since ocean waves rarely have wavelengths higher than 200 m, and the open ocean is several thousand meters deep, the wave base does not frequently interact with the ocean's bottom. However, as waves approach the much shallower water near the shore, they start to "feel" the bottom, and they are affected by that interaction. The wave "orbits" are both flattened and slowed by dragging, and the implications are that the wave amplitude (height) increases, and the wavelength decreases (the waves become much steeper). The ultimate result of this is that the waves lean forward, and eventually break. (4)

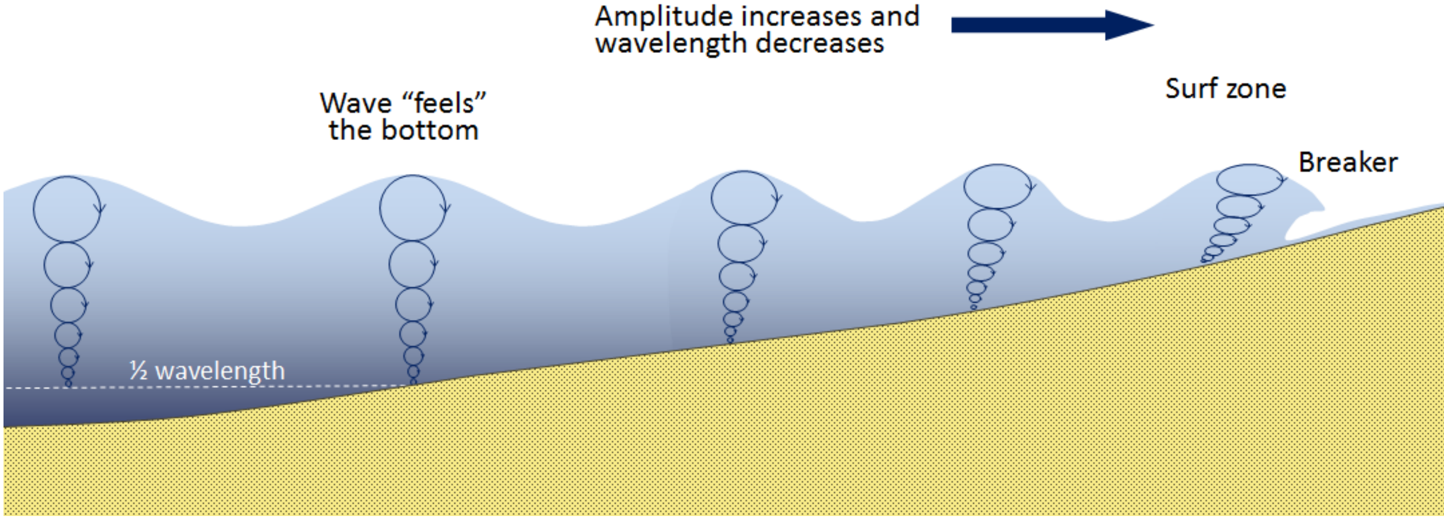


Figure 8.2.2 Waves approaching shore flatten. S. Earle, CC-BY

Shoreline Currents

Waves usually approach the shore at an angle, and this means that one part of the wave feels the bottom sooner than the rest of it, so the part that feels the bottom first slows down first. In open water, these waves had wavelengths close to 100 m. In the shallow water closer to shore, the wavelengths decreased to around 50 m, and in some cases, even less. Even though they bend and become nearly parallel to the shore, most waves still reach the shore at a small angle, and as each one arrives, it pushes water along the shore, creating what is known as a **longshore current** within the **surf zone** where waves are breaking. (3)

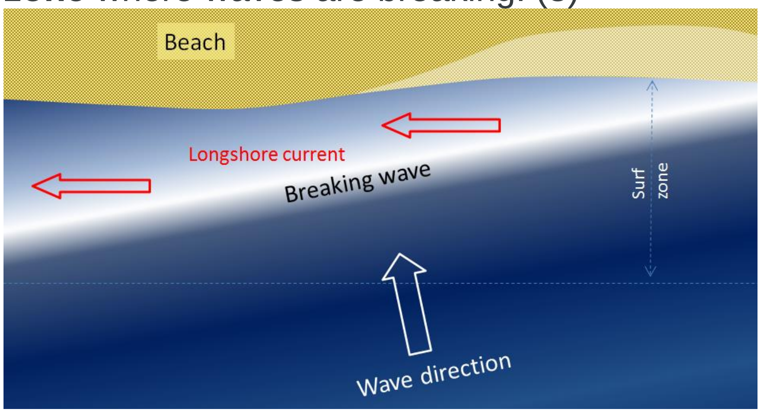


Figure 8.2.3 Formation of Longshore Current. S. Earle, CC-BY

Another significant effect of waves reaching the shore at an angle is that when they wash up onto the beach, they do so at an angle, but when that same wave water washes back down the beach, it moves straight down the slope of the beach. Figure 8.2.2 shows the upward-moving water, known as the **swash**, pushes sediment particles along the beach, while the downward-moving water, the **backwash**, brings them straight back. With every wave that washes up and down the beach, particles of sediment are moved along the beach in a zigzag pattern. (1)

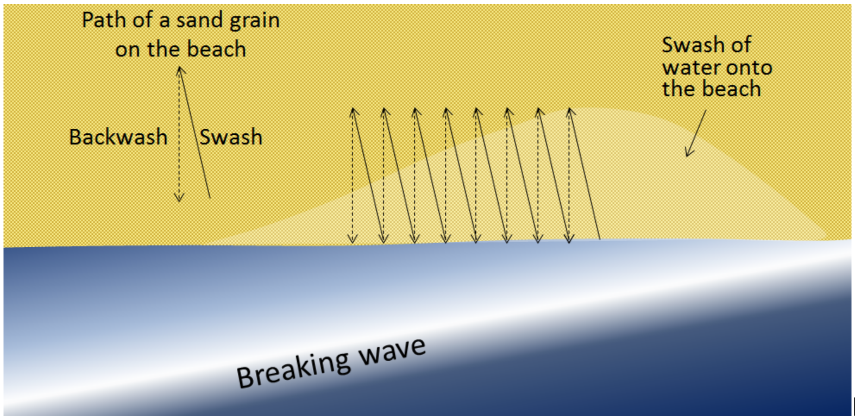


Figure 8.2.4 The movement of particles on a beach as a result of swash and backwash. S. Earle, CC-BY

The combined effects of sediment transport within the surf zone by the longshore current and sediment movement along the beach by swash and backwash is known as **longshore drift**. Longshore drift moves a tremendous amount of sediment along coasts (both oceans and large lakes) around the world, and it is responsible for creating a variety of depositional features. A **rip current** is another type of current that develops in the nearshore area and has the effect of returning water that has been pushed up to the shore by incoming waves. If part of a beach does not have a strong unidirectional longshore current, the rip currents may be fed by longshore currents going in both directions. (1)

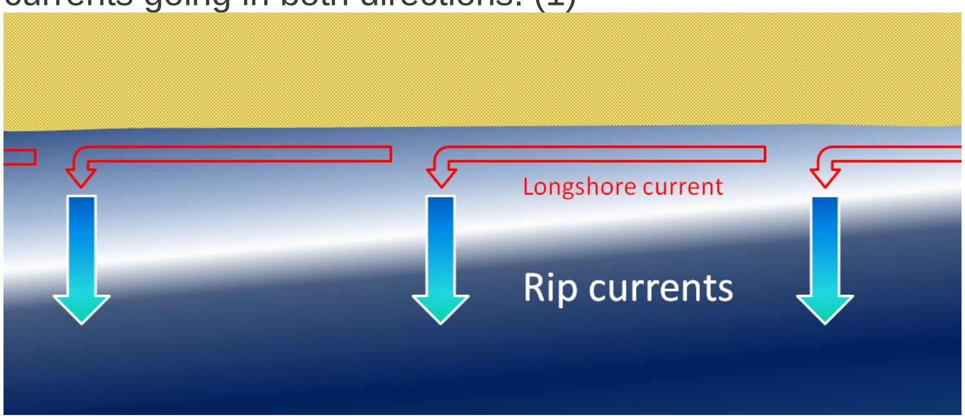


Figure 8.2.5 The formation of rip currents on a beach with strong surf. S. Earle, CC-BY

Hazards associated with Waves and Currents

Any place where the ocean and land are in contact can pose a risk of hazard to people. Rip currents flow straight out from the shore and are fed by the longshore currents. They die out quickly outside the surf zone but can be dangerous to swimmers who get caught in them. Typically they reach speeds of 1 to 2 feet per second, but some have been measured at 8 feet per second, faster than an Olympic swimmer. Because rip currents move perpendicular to shore and can be very strong, beach swimmers need to be careful. A person caught in a rip can be swept away from shore very quickly. The best way to escape a rip current is by swimming parallel to the shore instead of towards it, since most rip currents are less than 80 feet wide. A swimmer can also let the current carry him or her out to sea until the force weakens, because rip currents stay close to shore and usually dissipate just beyond the line of breaking waves. Occasionally, however, a rip current can push someone hundreds of yards offshore. The most important thing to remember if you are ever caught in a rip current is not to panic. Continue to breathe, try to keep your head above water, and don't exhaust yourself fighting against the force of the current. (6)

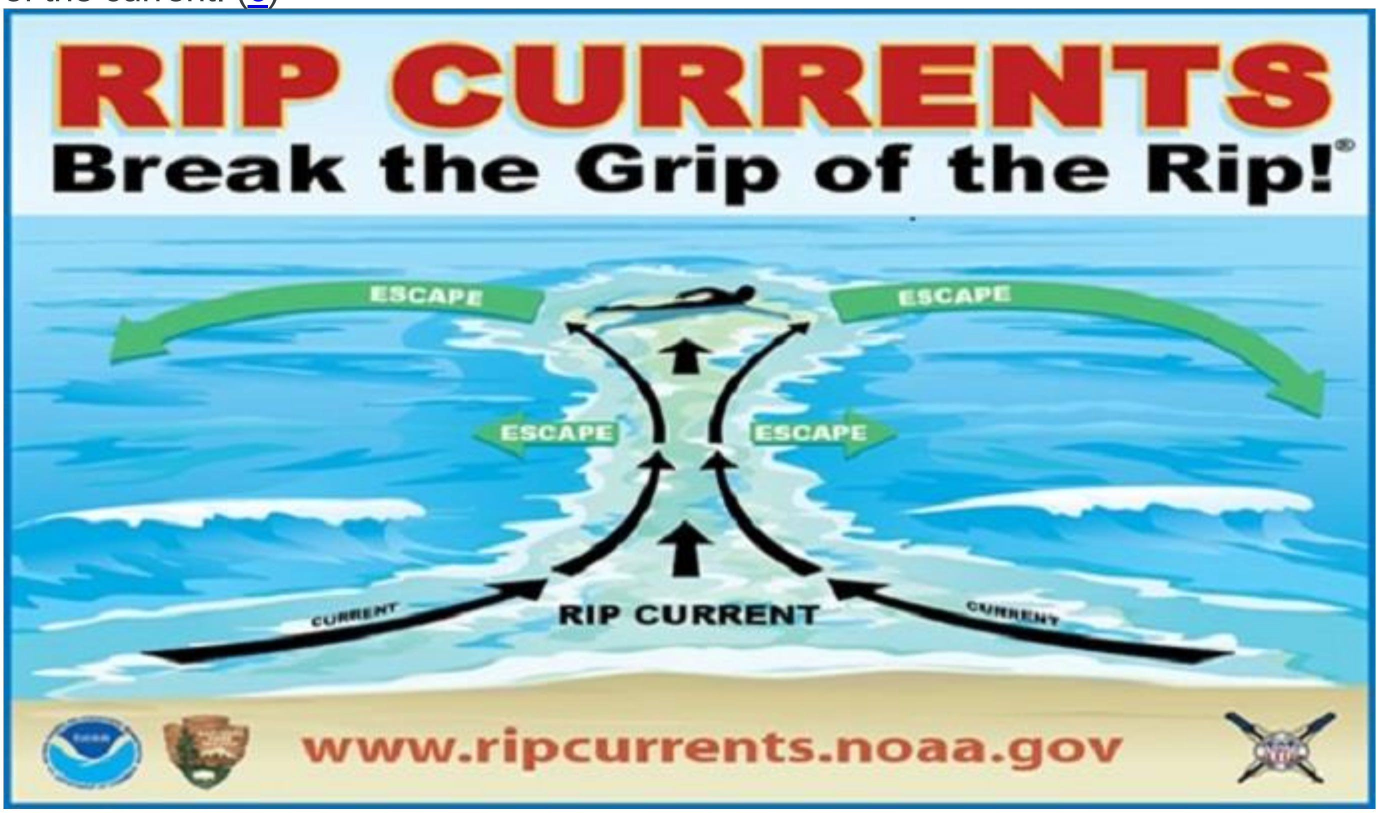


Figure 8.2.6 Rip Currents National Weather Service, Public Domain.

Storm Surge

Some of the damage done by storms is from **storm surges**. The water piles up at a shoreline as storm winds push waves into the coast. Storm surge may raise sea level as much as 7.5 m (25 ft), which can be devastating in a shallow land area when winds, waves, and rain are heavy. Storm surges can cause extensive damages, eroding beaches and coastal highways, destroying buildings and boats, and affecting inland rivers and lakes.

Tsunamis

A particular type of wave is generated by an energetic event affecting the seafloor, such as earthquakes, submarine landslides, and volcanic eruptions. Called **tsunamis**, these waves are created when a portion of the seafloor is suddenly elevated by movement in the crustal rocks below that are involved in an earthquake. The water is suddenly lifted, and a wave train spreads out in all directions from the mound carrying enormous energy and traveling very fast (hundreds of miles per hour). A series of long-period waves (on the order of tens of minutes) that are usually generated by an impulsive disturbance that displaces massive amounts of water, such as an earthquake occurring on or near the sea floor. Underwater volcanic eruptions and landslides can also cause tsunami. The resultant waves much the same as waves propagating in a calm pond after a rock is tossed. While traveling in the deep oceans, tsunami have extremely long wavelengths, often exceeding 50 nm, with small amplitudes (a few tens of centimeters) and negligible wave steepness, which in the open ocean would cause nothing more than a gentle rise and fall for most vessels, and possibly go unnoticed. Tsunami travel at very high speeds, sometimes in excess of 400 knots. Across the open oceans, these high-speed waves lose very little energy. As tsunami reach the shallow waters near the coast, they begin to slow down while gradually growing steeper, due to the decreasing water depth, much in the same way that wind waves form (Figure 8.2.1). The building walls of destruction can become extremely large in height, reaching tens of meters or more as they reach the shoreline. The effects can be further amplified where a bay, harbor, or lagoon funnels the waves as they move inland. Large tsunami have been known to rise to over 100 feet! The amount of water and energy contained in tsunami can have devastating effects on coastal areas. (6)

8.3 Ocean Currents

Surface Currents

Ocean water moves in predictable ways along the ocean surface. **Surface currents** can flow for thousands of kilometers and can reach depths of hundreds of meters. These surface currents do not depend on the weather; they remain unchanged even in large storms because they depend on factors that do not change. (2)

Surface currents are created by three things: global wind patterns, the rotation of the earth, and ocean basins' shape. Surface currents are significant because they distribute heat around the planet and are a significant factor influencing climate around the globe.

"What Causes Ocean Currents." story map by Esri.

Global Wind Currents

Winds on Earth are either global or local. **Global winds** blow in the same directions all the time and are related to the unequal heating of Earth by the Sun, that is that more solar radiation strikes the equator than the polar regions, and the rotation of the Earth called the Coriolis effect. The causes of the global wind patterns will be described later when we look at the atmosphere. (2) Water in the surface currents is pushed in the direction of the significant wind belts:

- **Trade winds** are consistent winds that flow east to west between the equator and 30 degrees North and 30 degrees South latitude.
- **Westerlies** are the prevailing winds that blow from the west in the middle latitudes.
- **Polar easterlies** are winds that flow from the east between 50 degrees and 60 degrees north and south latitude, as well as the north and south poles.

Rotation of the Earth

The wind is not the only factor that affects ocean currents. The **Coriolis effect** describes how Earth's rotation steers winds and surface ocean currents. The Coriolis effect causes freely moving objects to appear to move to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The objects themselves are moving straight, but the Earth is rotating beneath them, so they seem to bend. (2)

An example might make the Coriolis effect easier to visualize. If an airplane flies five hundred miles due north, it will not arrive at the city that was due north of it when it began its journey. Over the time it takes for the airplane to fly five hundred miles, that city moved, along with the Earth it sits on. Therefore, the airplane will arrive at a city to the west of the original city (in the Northern Hemisphere) unless the pilot has compensated for the change. So, to reach his intended destination, the pilot must also veer right while flying north.

As wind or ocean currents move, the Earth spins underneath it. As a result, an object moving north or south along the Earth will appear to move in a curve, instead of in a straight line. Wind or water that travels toward the poles from the equator is deflected to the east, while wind or water that travels toward the equator from the poles gets bent to the west. The Coriolis effect bends the direction of surface currents to the right in the Northern Hemisphere and left in the Southern Hemisphere. (2)

Deep Currents

Thermohaline circulation drives deep ocean circulation. Thermo means heat, and haline refers to salinity. Differences in temperature and salinity change the density of seawater. Thermohaline circulation is the result of density differences in water masses because of their different temperature and salinity. (5)

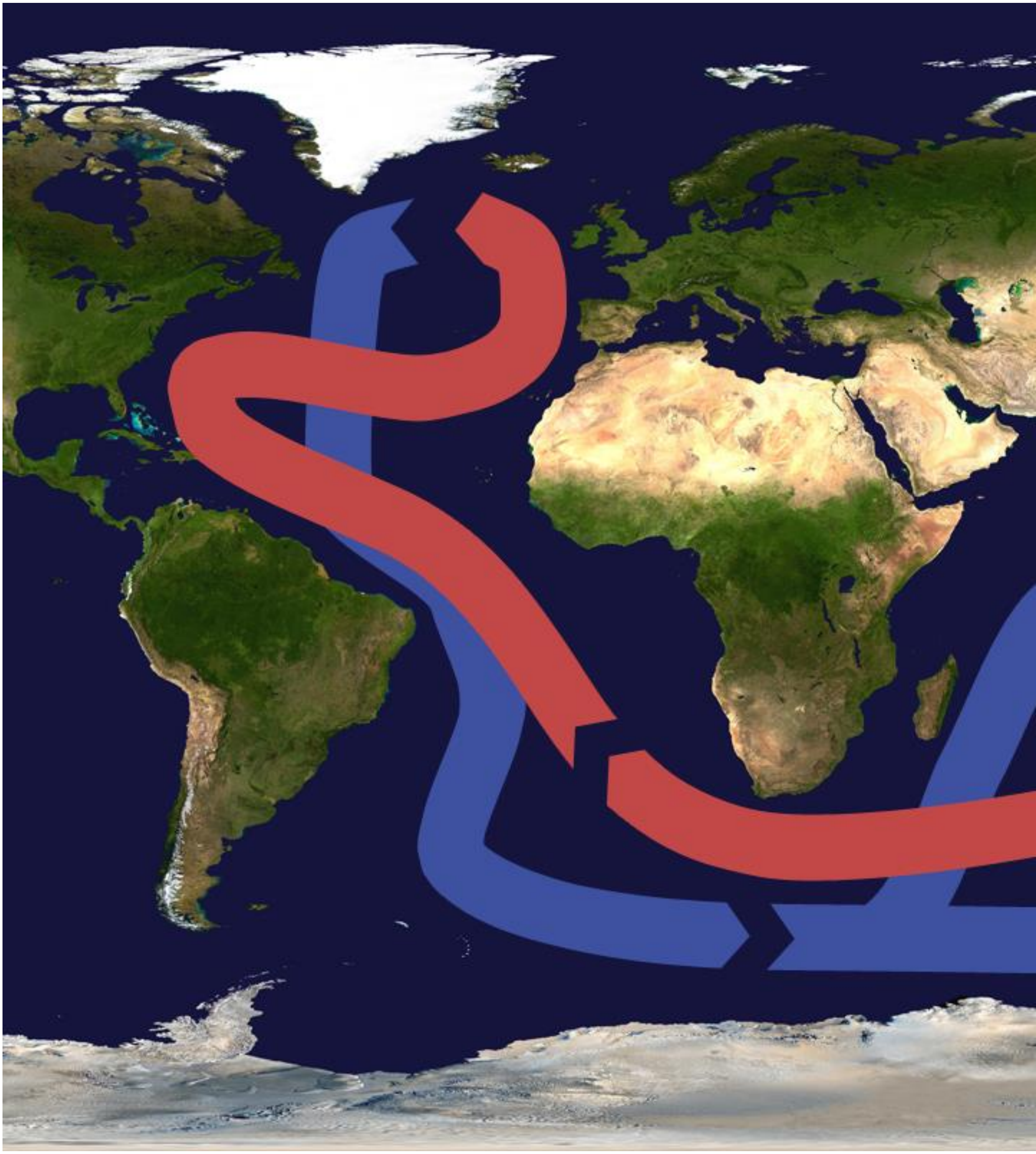


Figure 8.3.1 Thermohaline Circulation , Wikicommons, CC-BY-SA

Lower temperature and higher salinity yield the densest water. When a volume of water is cooled, the molecules move less vigorously, so the same number of molecules takes up less space, and the water is denser. If salt is added to a volume of water, there are more molecules in the same volume, so it is denser. Changes in temperature and salinity of seawater take place at the surface. Water becomes dense near the poles. Cold polar air cools the water and lowers its temperature, increasing its salinity. Freshwater freezes out of seawater to become sea ice, which also increases the salinity of the remaining water. This frigid, very saline water is very dense and sinks, a process called **downwelling**. (1)

Two things then happen. The dense water pushes deeper water out of its way, and that water moves along the bottom of the ocean. This deep-water mixes with less dense water as it flows. Surface currents move water into the space vacated at the surface where the dense water sank. Water also sinks into the deep ocean off Antarctica. Since unlimited amounts of water cannot sink to the ocean's bottom, water must rise from the deep ocean to the surface somewhere. This process is called **upwelling**. (1)

Upwelling occurs along the coast when the wind blows water strongly away from the shore. This leaves a void that is filled with deep water that rises to the surface. Upwelling is significant where it occurs. During its time on the bottom, the cold deep water has collected nutrients that have fallen through the water column. Upwelling brings those nutrients to the surface. That nutrient supports the growth of plankton and forms the base of a vibrant ecosystem. California, South America, South Africa, and the Arabian Sea all benefit from offshore upwelling. Upwelling also takes place along the equator between the North and South Equatorial Currents. Winds blow the surface water north and south of the equator, so deep water undergoes upwelling. The nutrients rise to the surface and support a great deal of life in the equatorial oceans. (2)

"How Ocean Currents Impact the World" story map by Esri.

8.4 Topography and Landforms

Topography of the Sea Floor

Oceans cover 71% of Earth's surface and hold 97% of Earth's water. The water the oceans hold is critical to plate tectonics, volcanism, and, of course, life on Earth. We know more about the surface of the Moon than the floor of the oceans. Whether this is true or not, the critical point is that the ocean floor is covered with an average of nearly 4,000 m of water, and it is pitch black below a few hundred meters, so it is not easy to discover what is down there. We know a lot more about the oceans than we used to, but there is still a great deal more to discover. (4)

Earth has had oceans for a very long time, dating back to the point where the surface had cooled enough to allow liquid water, only a few hundred million years after Earth's formation. At that time, there were no continental rocks, so the water that was here was likely spread out over the surface in one giant (but relatively shallow) ocean. (4)

We examined the seafloor's topography from the perspective of plate tectonics, but here we are going to take another look at the essential features from an oceanographic perspective. The essential features are the extensive continental shelves less than 250 m deep (pink); the vast deep abyssal plains between 3,000 and 6,000 m deep (light and dark blue); the mid-Atlantic ridge, in many areas shallower than 3,000 m; and the deep ocean trench north of Puerto Rico. (4) These features are connected by continental slopes, which is the transition area between continental shelves and abyssal planes.

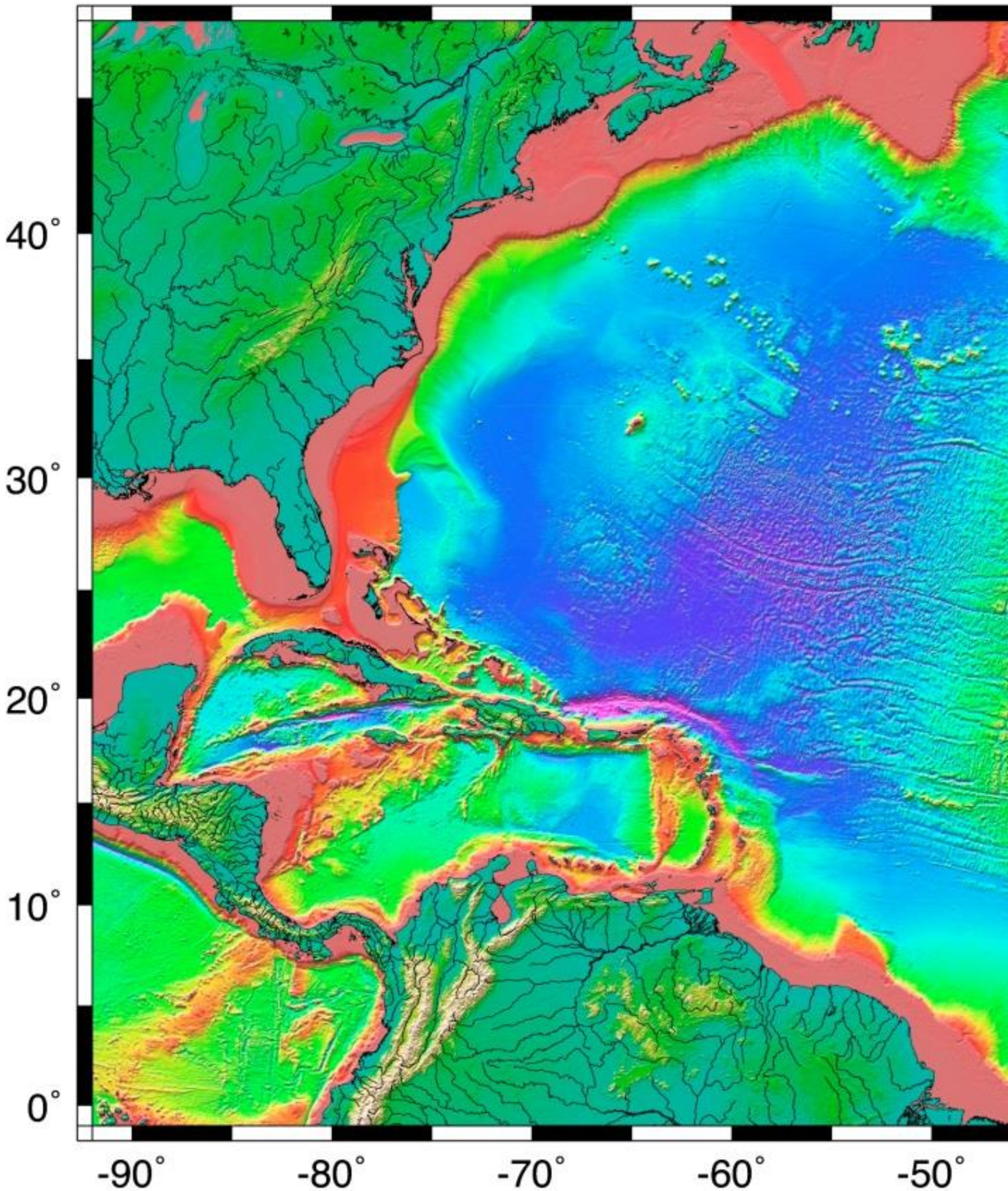

40°
30°
20°
10°
0°
-90°
-80°
-70°
-60°
-50°

Figure 8.4.1 Topography of the Atlantic Ocean Sea Floor NASA, Public Domain.

Of course, it is more complicated than this, even in this simplified form. Figure 8.4.2 shows a generalized cross-section of the Pacific Ocean which has short continental shelves that quickly turn to continental slopes, dropping from about 200 m to several thousand meters over a distance of a few hundred kilometers. The continental slopes connect to abyssal plains – exceedingly flat and from 4,000 m to 6,000 m deep; volcanic seamounts and islands; and trenches at subduction zones that are up to 11,000 m deep.

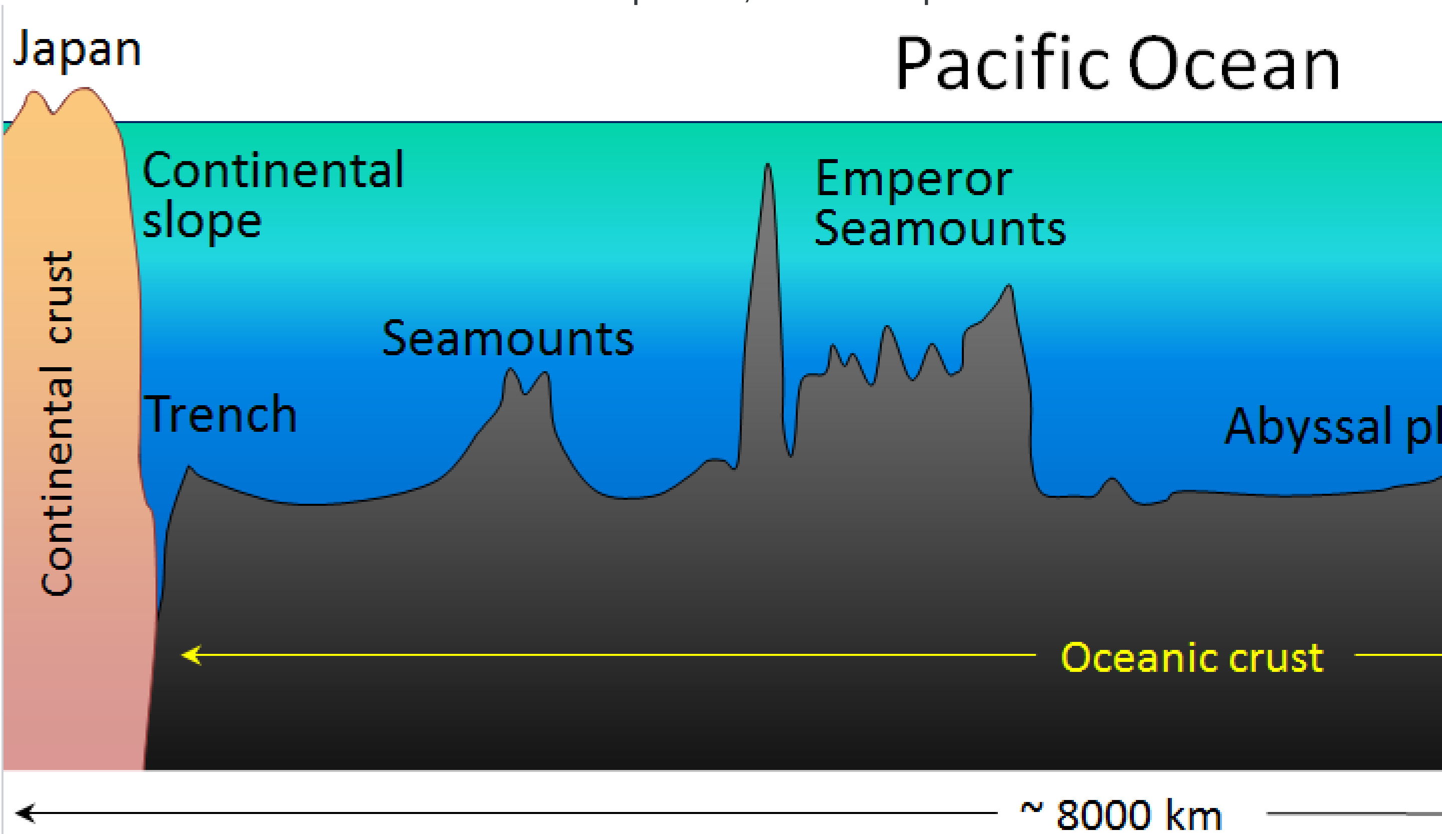


Figure 8.4.2 Generalized Topography of the Pacific Ocean Sea Floor, S. Earle CC-BY-4.0

The ocean floor is entirely underlain by mafic oceanic crust, while the continental slopes are underlain by felsic continental crust (mostly granitic and sedimentary rocks). Moreover, the denser oceanic crust floats lower on the mantle than continental crust does, and that is why oceans are oceans. Although the temperature of the ocean surface varies widely, from a few degrees either side of freezing in polar regions to over 25°C in the tropics, in most parts of the ocean, the water temperature is around 10°C at 1,000 m depth and about 4°C from 2,000 m depth to the bottom. (4)

The deepest parts of the ocean are within the subduction trenches, and the deepest of these is the Marianas Trench in the southwestern Pacific (near Guam) at 11,000 m. Other trenches in the southwestern Pacific are over 10,000 m deep; the Japan Trench is over 9,000 m deep, and the Puerto Rico and Chile-Peru Trenches are over 8,000 m deep. Shallow trenches tend to be that way because they have significant sediment infill. There is no recognizable trench along the subduction zone of the Juan de Fuca Plate because it has been filled with sediments from the Fraser and Columbia Rivers. (4)

Landforms of Coastal Erosion

Large waves crashing onto a shore bring a tremendous amount of energy that has a significant eroding effect, and several unique erosion features commonly form on rocky shores with strong waves. When waves approach an irregular shore, they are slowed down to varying degrees, depending on differences in the water depth, and as they slow, they are bent or refracted. That energy is evenly spaced out in the deep water, but because of refraction, the waves' energy, which moves perpendicular to the wave crests, is being focused on the **headlands**. On irregular coasts, the headlands receive much more wave energy than the intervening bays, and thus they are more strongly eroded. The result of this is **coastal straightening**. An irregular coast, like the west coast of Vancouver Island, will eventually become straightened, although that process will take millions of years. (4)

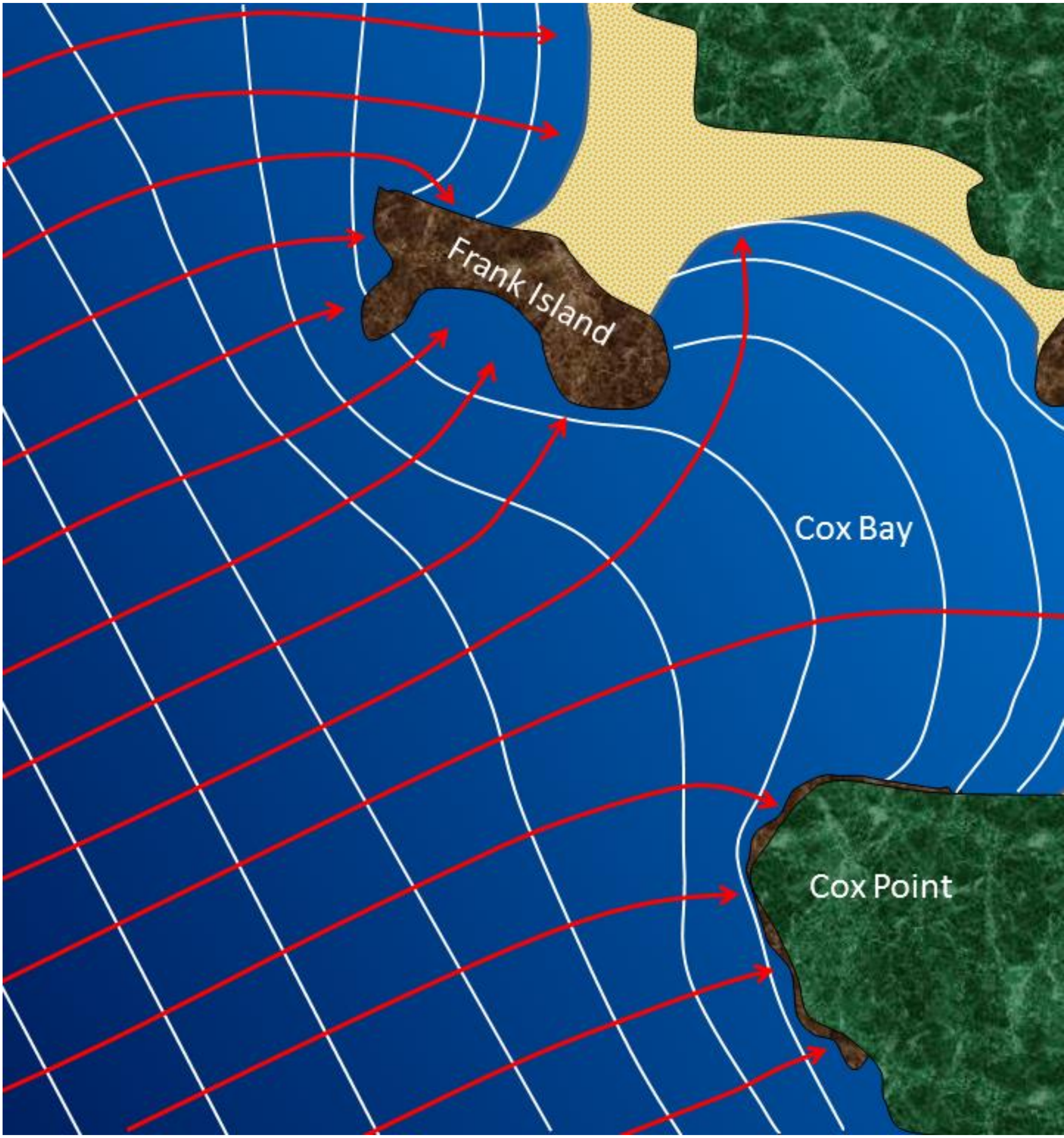


Figure 8.4.3 Coastal Straightening. S. Earle, CC-BY

Wave erosion is highest in the surf zone, where the wave base is impinging strongly on the seafloor and where the waves are breaking. The result is that the substrate in the surf zone is typically eroded to a flat surface known as a **wave-cut platform**. A wave-cut platform extends across the intertidal zone. (4)

Resistant rock that does not get eroded entirely during the formation of a wave-cut platform will remain behind to form a **stack**. Here the different layers of the sedimentary rock have different resistance to erosion. The upper part of this stack is made up of rock that resisted erosion, and that rock has protected a small pedestal of underlying softer rock. The softer rock will eventually be eroded, and the big rock will become just another boulder on the beach.

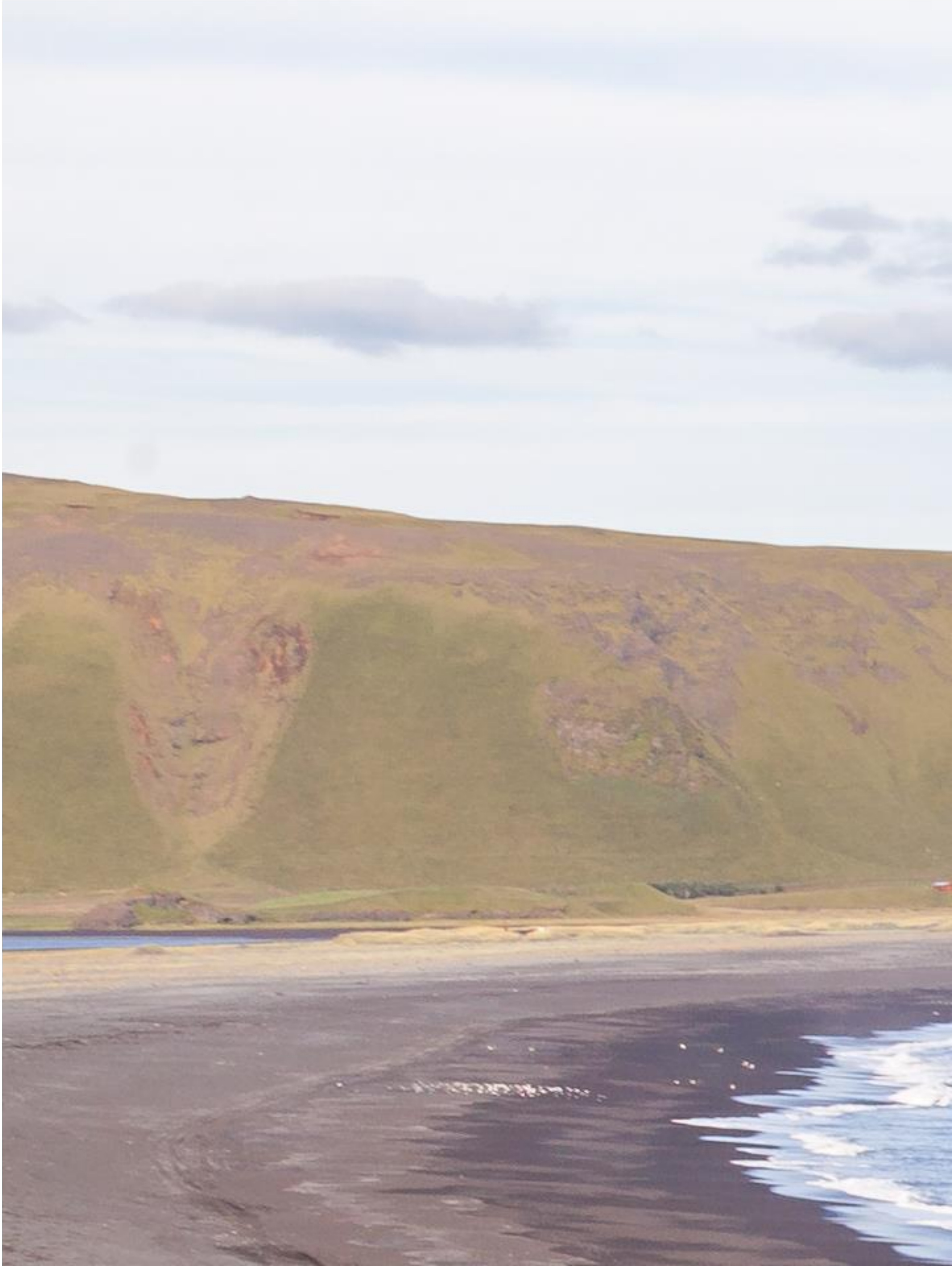


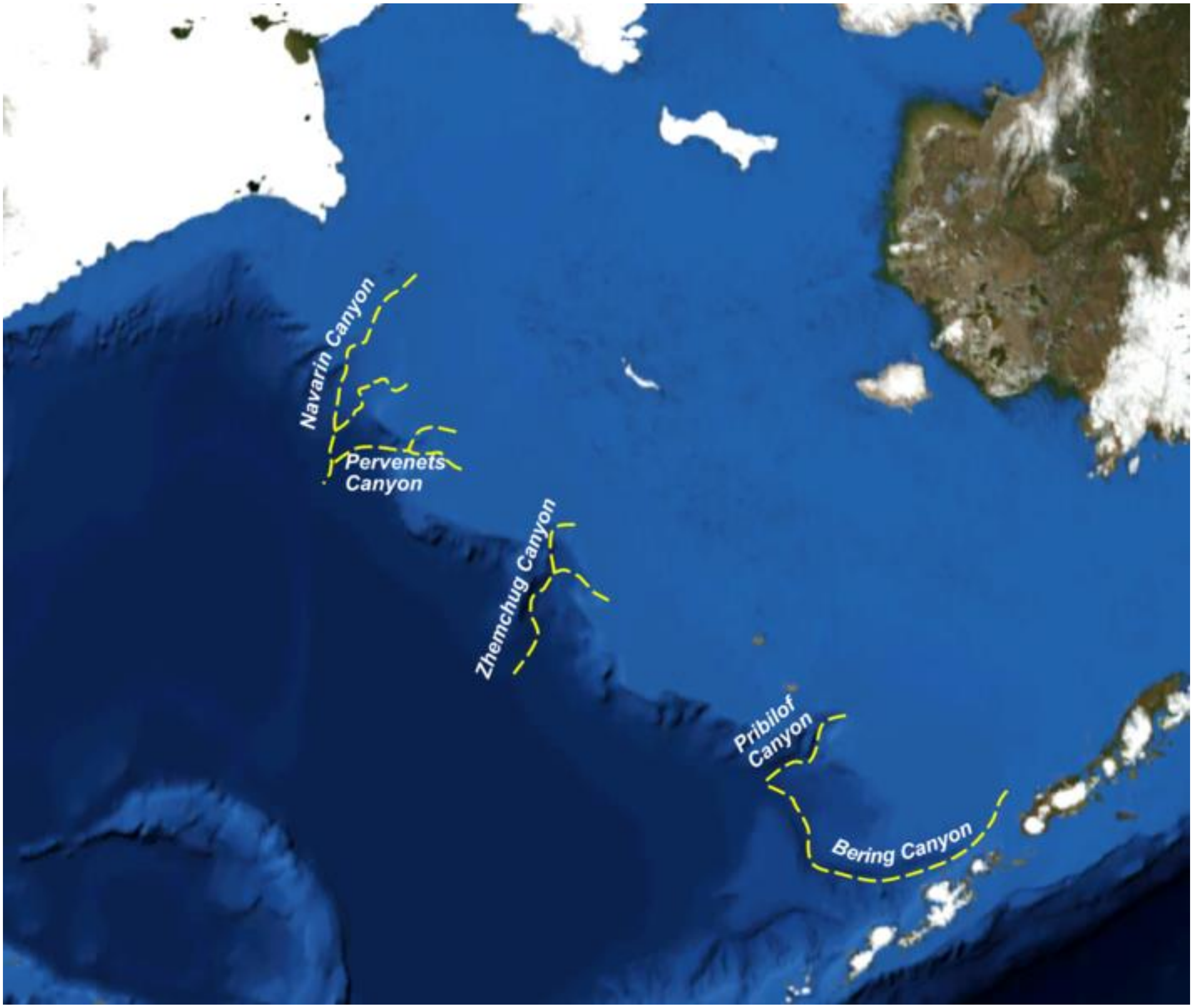
Figure 8.4.4 Basalt Sea Stack. Wikicommons, CC-BY-SA

Arches and **sea caves** are related to stacks because they all form because of the erosion of non-resistant rock. (4)

Figure 8.4.5 Akun Island Basalt Sea Cave. S. Hillebrand, US Fish and Wildlife Service, Public Domain

Submarine Canyons

Submarine canyons are narrow and deep canyons located in the marine environment on continental shelves. They typically form at the mouths of sizeable landward river systems, both by cutting down into the continental shelf during low sea levels and by continual material slumping or flowing down from the mouth of the river or a delta. Underwater currents rich in sediment pass through the canyons, erode them and drain onto the ocean floor. Steep delta faces and underwater flows of sediments are released down the continental slope as underwater landslides, called turbidity flows. The erosive action of this type of flow continues to cut the canyon, and eventually, fan-shaped deposits develop on the ocean floor beyond the continental slope. (4)



8.5.6 Berignian Margin Canyons. Wikicommons, BB-CY-SA

Landforms of Coastal Deposition

Some coastal areas are dominated by erosion, an example being the Pacific coast of Canada and the United States, while others are dominated by deposition, examples being the Atlantic and Caribbean coasts of the United States. However, on almost all coasts, deposition and erosion are happening to vary degrees most of the time, although in various places. On deposition-dominant coasts, the coastal sediments are still being eroded from some areas and deposited in others.

The main factor in determining if the coast is dominated by erosion or deposition is its history of tectonic activity. A coast like that of British Columbia is tectonically active, and compression and uplift have been going on for tens of millions of years. This coast has also been uplifted during the past 15,000 years by isostatic rebound due to deglaciation. The coasts of the United States along the Atlantic and the Gulf of Mexico have not seen significant tectonic activity in a few hundred million years, and except in the northeast, have not experienced post-glacial uplift. These areas have relatively little topographic relief, and there is now minimal erosion of coastal bedrock. (4)

On coasts dominated by depositional processes, most of the sediment being deposited typically comes from large rivers. An obvious example is where the Mississippi River flows into the Gulf of Mexico at New Orleans; another is the Fraser River in Vancouver. No large rivers bring sandy sediments to the west coast of Vancouver Island, but there are still long and wide sandy beaches there. In this area, most of the sand comes from glaciofluvial sand deposits situated along the shore behind the beach, and some come from the erosion of the rocks on the headlands. (4)

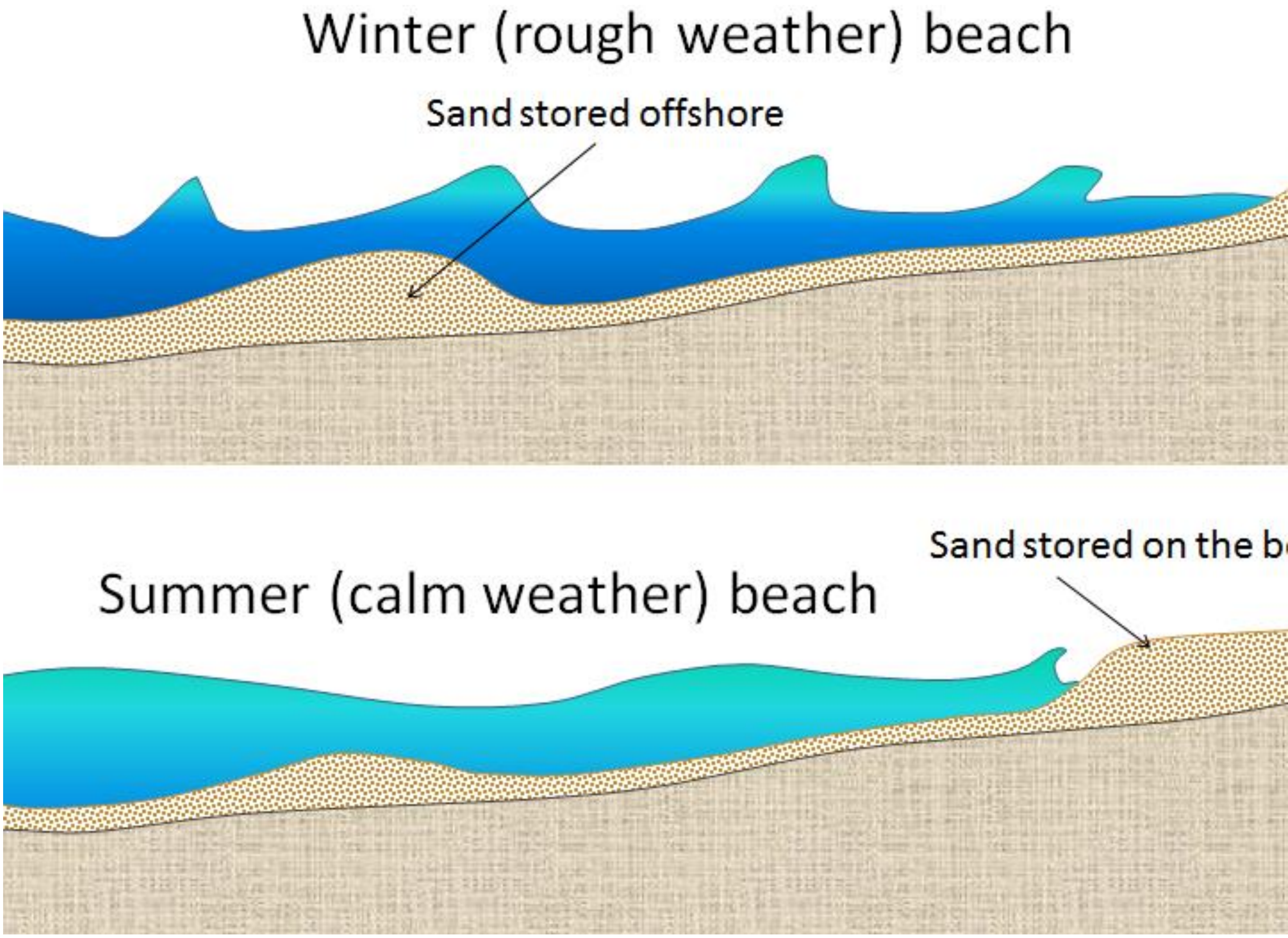


Figure 8.4.7 Winter and Summer Beach Deposition by S. Earle, CC-BY

Most beaches go through a seasonal cycle because conditions change from summer to winter. In summer, sea conditions are calm with long-wavelength, low-amplitude waves generated by distant winds. Winter conditions are rougher, with shorter-wavelength, higher-amplitude waves caused by strong local winds. As seen in Figure 8.4.7, the heavy seas of winter gradually erode sand from beaches, moving it to an underwater sandbar offshore. The gentler waves of summer gradually push this sand back toward the shore, creating a broader and flatter beach. (4)

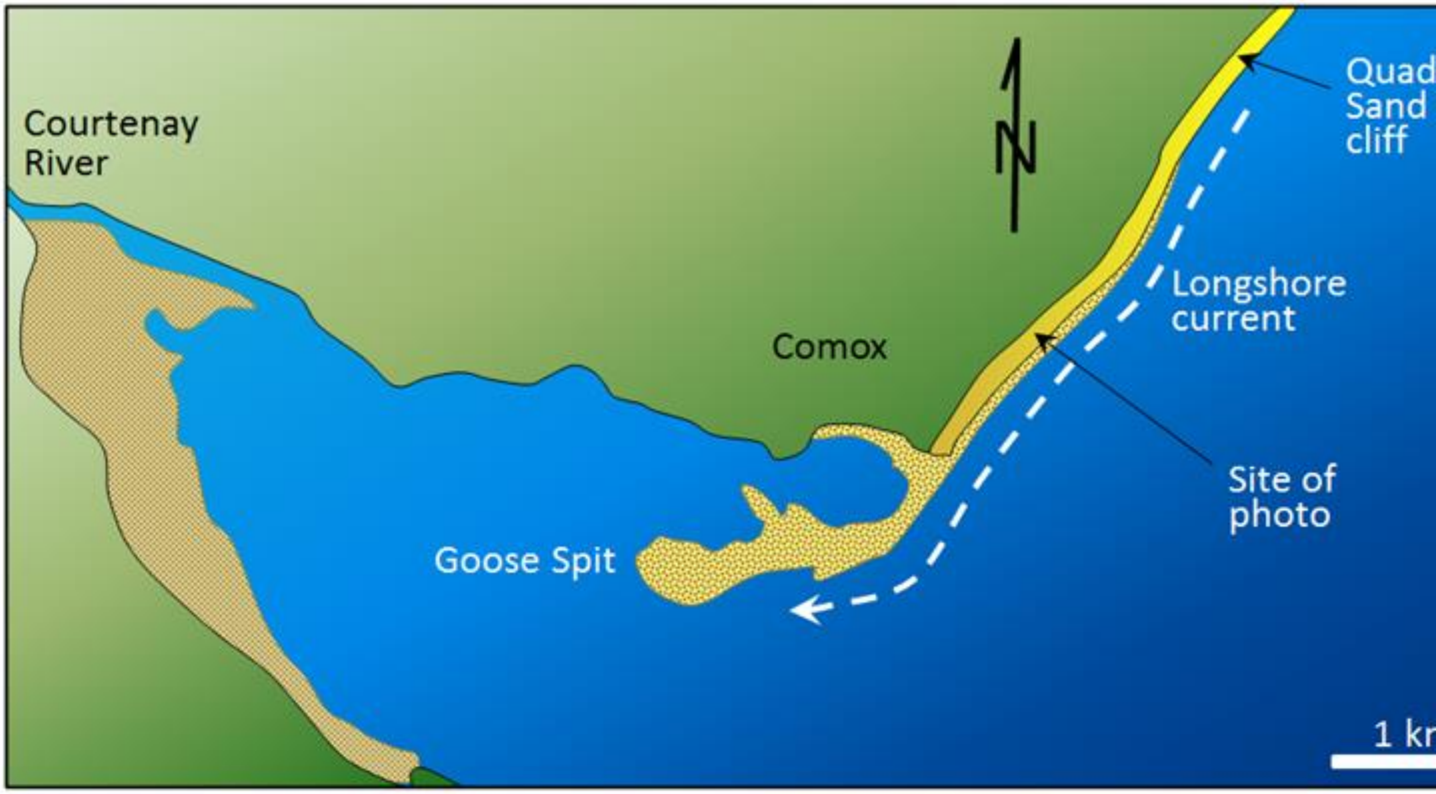


Figure 8.4.8 Goose Spit at Comox on Vancouver Island. U.S. Fish and Wildlife Service, Public Domain.

The evolution of sandy depositional features on seacoasts is primarily influenced by waves and currents, especially longshore currents. As sediment is transported along a shore, either it is deposited on beaches, or it creates other depositional features. For example, a spit is an elongated sandy deposit that extends out into open water in the direction of a longshore current. (4)

A spit that extends across a bay to the extent of closing, or almost closing it off, is known as a baymouth bar. Most bays have streams flowing into them, and since this water must get out, rarely, a baymouth bar will completely close the entrance to a bay. In areas where there is sufficient sediment being transported, and there are nearshore islands, a tombolo may form.

Tombolos are common where islands are abundant, and they typically form where there is a wave shadow behind a nearshore island. This becomes an area with reduced energy, and so the longshore current slows, and sediments accumulate. Eventually, enough sediments accumulate to connect the island to the mainland with a tombolo. (4)


Figure 8.4.9 Barrier Islands of South Shore Long Island. L. Chiou, CC-BY-SA

In areas where coastal sediments are abundant and coastal relief is low (because there has been little or no recent coastal uplift), it is common for barrier islands to form. **Barrier islands** are elongated islands composed of sand that form a few kilometers away from the mainland. They are common along the US Gulf Coast from Texas to Florida, and along the US Atlantic Coast from Florida to Massachusetts. North of Boston, the coast becomes rocky, partly because that area has been affected by a post-glacial crustal rebound. (4) Barrier islands do an excellent job of blocking incoming storm surges from hurricanes, but since they are made almost entirely of sand they shift and move with every storm event. Though they are largely unstable for building and infrastructure, many people live on barrier islands and have to regularly face coastal hazards. The 2000 U.S. Census estimates that there are 1.4 million people living on barrier islands, with a population density of three times that of the coast.

8.5 Sea-Level Change

Mechanisms

Sea-level change has been a feature on Earth for billions of years, and it has important implications for coastal processes and both erosional and depositional features. There are three primary mechanisms of sea-level change, as described below.

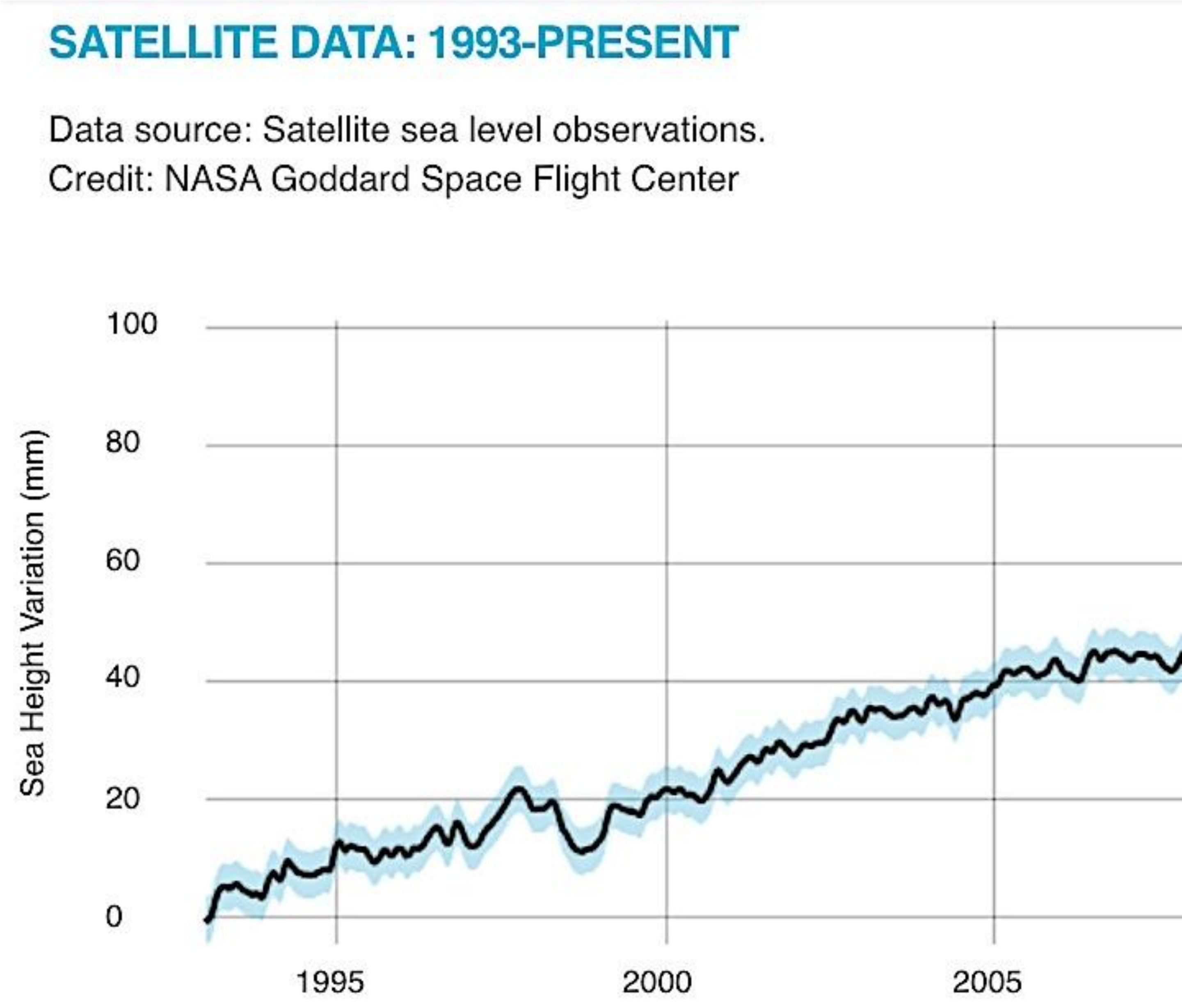


Figure 8.5.1 Satellite Sea-level observations. NASA (2019), Public Domain

Eustatic

Eustatic sea-level changes are global sea-level changes related to changes in the volume of glacial ice on land or changes in the shape of the seafloor caused by plate tectonic processes. For example, changes in the rate of mid-ocean spreading will change the seafloor's shape near the ridges, which affects sea level. Over the past 20,000 years, there have been approximately 125 meters (410 feet) of eustatic sea-level rise due to glacial melting. Most of that took place between 15,000 and 7,500 years ago during the significant melting phase of the North American and Eurasian Ice Sheets. At around 7,500 years ago, the rate of glacial melting and sea-level rise decreased dramatically, and since that time, the average rate has been in the order of 0.7 mm/year. Anthropogenic climate change led to an accelerating sea-level rise starting around 1870. Since that time, the average rate has been 1.1 mm/year, but it has been gradually increasing. Since 1992, the average rate has been 3.2 mm/year. (4)

Isostatic

Isostatic sea-level changes are local changes caused by subsidence or uplift of the crust related either to changes in the amount of ice on the land or to growth or erosion of mountains. Almost all of Canada and parts of the northern United States were covered in thick ice sheets at the peak of the last glaciation. Following the melting of this ice, there has been an isostatic rebound of continental crust in many areas. This ranges from several hundred meters of rebound in the central part of the Laurentide Ice Sheet (around Hudson Bay) to 100 m to 200 m in the peripheral parts of the Laurentide and Cordilleran Ice Sheets – in places such as Vancouver Island and the mainland coast of BC. Although the global sea level was about 130 m lower during the last glaciation, the glaciated regions were depressed at least that much in most places, and more than that in places where the ice was thickest. (7)

Tectonic

Tectonic sea-level changes are local changes caused by tectonic processes. The subduction of the Juan de Fuca Plate beneath British Columbia creates tectonic uplift (about 1 mm/year) along the western edge of Vancouver Island, although much of this uplift is likely to be reversed when the next sizeable subduction-zone earthquake strikes. (4)

Emergent and Submergent Coasts

Coastlines that have a relative fall in sea level, either caused by tectonics or sea-level change, are called **emergent**. Where the shoreline is rocky, with a sea cliff, waves refracting around headlands attack the rocks behind the point of the headland.

They may cut out the rock at the base forming a sea arch that may collapse to isolate the point as a stack. Rocks behind the stack may be eroded, and sand eroded from the point collects behind it, forming a tombolo, a sand strip that connects the stack to the shoreline. Where sand supply is low, wave energy may erode a wave-cut platform across the surf zone, exposed as bare rock with tidal pools at low tide. Sea cliffs tend to be persistent features as the waves cut away at their base, and higher rocks calve off by mass wasting. If the coast is emergent, these erosional features may be elevated compared to the wave zone. Wave-cut platforms become marine terraces, with remnant sea cliffs inland from them. (4)

Tectonic subsidence or sea-level rise produces a **submergent** coast. Features associated with submergence coasts include estuaries, bays, and river mouths flooded by the higher water. **Fjords** are ancient glacial valleys now flooded by post-Ice Age sea level rise. Barrier islands form parallel to the shoreline from the old beach sands, often isolated from the mainland by lagoons behind them. Some scientists hypothesize that barrier islands formed by rising sea levels as the ice sheets melted after the last ice age. Accumulation of spits and far offshore bar formations are also mentioned as formation hypotheses for barrier islands.

Estuaries and fiords commonly characterize coastlines in areas where there has been a net sea-level rise in the geologically recent past. This valley was filled with ice during the last glaciation, and there has been a net rise in sea level here since that time. Uplifted wave-cut platforms or stream valleys characterize coastlines in areas where there has been a net sea-level drop in the geologically recent past. Uplifted beach lines are another product of relative sea-level drop, although these are difficult to recognize in areas with vigorous vegetation.

Backyard Geology: Sea-level changes recorded in rocks

While it seems fairly obvious that there are no real coastlines in Arizona currently, their existence is preserved in rocks throughout the state. These ancient deposits imply that they were formed in a similar environment as the rocks of present day, so there must have been oceans and shorelines throughout Arizona in the past.

Figure 8.5.2 Rocks of the Grand Canyon show different environments where they were deposited

Figure 8.5.2 shows the three uppermost layers of the Grand Canyon. Though these layers were deposited millions of years ago, they preserve the environments that were present at their time of deposition. The Kaibab Formation, the youngest set of rocks found in the Grand Canyon, are a 270 million-year-old limestone that was deposited in a shallow marine (ocean) environment. The Toroweap Formation was formed in an intertidal zone, as sea-level changed several times. The older Coconino Sandstone is a 275 million-year-old wind-blown sand which forms a dramatic cliff in the present day. Together, these rock show that sea-level changed dramatically in just 5 million years, and much of Arizona was entirely under water!

8.6 Human Influences

Mitigation and Modification

There are various modifications that we make to influence beach processes for our purposes. Sometimes these changes are effective and may appear to be beneficial, although in most cases, there are unintended negative consequences that we do not recognize until much later. (4)

Seawalls

Seawalls help limit erosion and are enjoyable amenities for the public, but they have geological and ecological costs. When a shoreline is “hardened” in this way, crucial marine habitats are lost, and sediment production is reduced, which can affect beaches elsewhere. Seawalls also affect the behavior of waves and longshore currents, sometimes with negative results. (1)

Figure 8.6.1 Seawall. Wikimedia Commons, Public Domain.

Groins and Jetties

Groins have an effect similar to that of breakwaters, although groins are constructed perpendicular to the beach, and they trap sediment by slowing the longshore current. Most of the sediment that forms beaches along our coasts comes from rivers, so if we want to take care of the beaches, we have to take care of rivers. When a river is dammed, its sediment load is deposited in the resulting reservoir, and for the century or two, while the reservoir is filling up, that sediment cannot get to the sea. During that time, beaches (including spits, baymouth bars, and tombolos) within tens of kilometers of the river's mouth (or more in some cases) are at risk of erosion. (4)

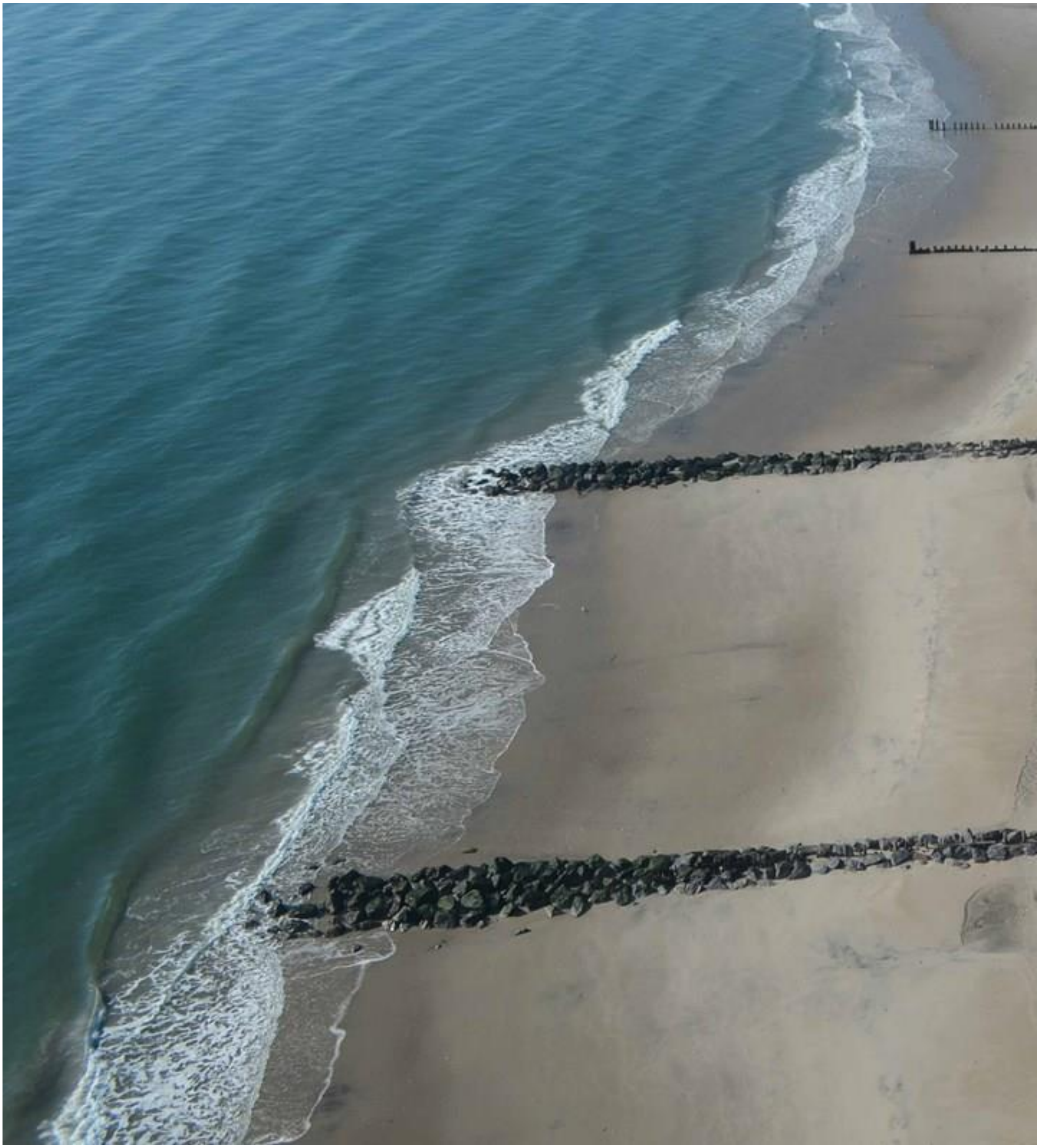


Figure 8.6.2 [Groins and Jetties](). [National Park Service, Public Domain]().

Coasts are prime real estate land that attracts the development of beach houses, condominiums, and hotels. This kind of interest and investment leads to ongoing efforts to manage the natural processes in coastal areas. Humans who find longshore drift is removing sand from their beaches often use groins in an attempt to retain it. (1)

Similar but smaller than jetties, groins are bits of wood or concrete built across the beach perpendicular to the shoreline at the downstream end of one's property. Unlike jetties, they are used to preserve sand on a beach, rather than to divert it from an area. Sand erodes on the downstream side of the groin and collects against the upstream side. Every groin thus creates a need for another one downstream. The series of groins along a beach develops a scalloped appearance for the shoreline. (8)

Breakwaters

Figure 8.6.3 Breakwater off Long Beach, CA. GoogleEarth, Fair Use, modified by M. Wilson

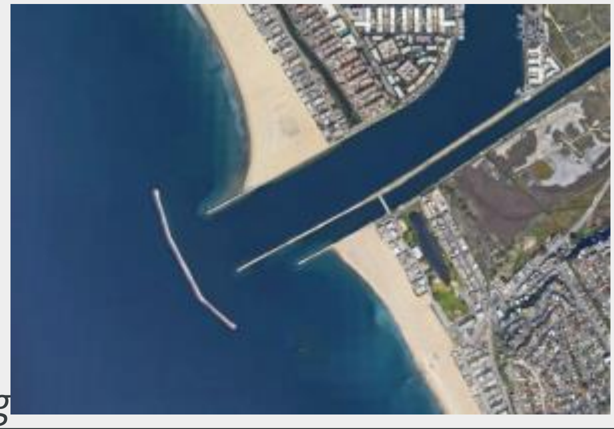
Another approach to reduce erosion or provide protected areas for boat anchoring is the construction of a breakwater, an offshore structure against which the waves break, leaving calmer waters behind it. Unfortunately, this means that waves can no longer reach the beach to keep the longshore drift of sand moving. The drift is interrupted, the sand is deposited in the quieter water, and the shoreline builds out, forming a tombolo behind the breakwater, eventually covering the structure with sand, rendering it obsolete. (1) During WWII, the U.S. Navy built a series of breakwaters just offshore of Long Beach, California, in order to maintain a deep port and serve as a deterrent to enemy submarines (Figure 8.6.3). While it served its purpose, it changed the dynamics of the beach itself, halting wave formation and destroying habitat. Additionally, trash and debris from the Los Angeles River builds up in the marina and cannot escape.

Beach Replenishment


8.6.4 Sand dredging pumping sand back to the beach. Wikimedia Commons, Public Domain

Sand for longshore drift and beaches comes from rivers flowing to the oceans from inland areas. Beaches may become starved of sand if sediment carried by streams and rivers is trapped behind dams. To mitigate, beach replenishment may be employed where sand is hauled from other areas by trucks or barges and dumped on the depleted beach. Unfortunately, this can disrupt the ecosystem that exists along the shoreline by exposing native creatures to foreign sandy material and foreign microorganisms and can even bring in foreign objects that impact humans on replenished beaches. Visitors to one replenished east coast beach found munitions and metal shards in the sand which had been brought from abandoned test ranges from which the sand had been dredged. (1)

Showcase your understanding



Coral Reefs and Bleaching

Anthropomorphic climate change has caused the oceans to change in temperature at an alarming rate. One of the side effects of this is coral bleaching. When corals are stressed by changes in conditions, they expel the symbiotic algae living in their tissues, causing them to turn completely white. While the coral is not yet dead, it is a sign of stress, and can lead to mass mortality.

Plastics in the Ocean

Plastic is the most prevalent type of marine debris found in our ocean and Great Lakes. Plastic debris can come in all shapes and sizes, but those that are less than five millimeters in length (or about the size of a sesame seed) are called “microplastics.” (1)

Sustainable Development

The ocean provides tremendous economic resources to the people of the world, and therefore humans will continue to affect it. Sustainable development of the ocean can occur with some efforts.