Chapter 17 Shorelines

Learning Objectives

After reading this chapter, completing the exercises within it, and answering the questions at the end, you should be able to:

- Summarize the factors that control wave formation and the important features of waves
- Explain how water is disturbed beneath a wave, and how that affects the behaviour of waves as they approach the shore
- Describe the origins of longshore currents and longshore drift
- Explain why some coasts are more affected by erosion than others and describe the formation of coastal erosional features, including stacks, arches, cliffs, and wave-cut platforms
- Explain the process of coastal straightening
- Summarize the origins of beaches, spits, baymouth bars, tombolos, and barrier islands
- Describe the origins of carbonate reefs
- Explain the various mechanisms of sea-level change (eustatic, isostatic, and tectonic) and the implications for coastal processes
- Compare the positive and negative implications of human interference with coastal processes

Figure 17.0.1 Chesterman Beach near Tofino on the west coast Vancouver Island. The strip of sediment connecting the main beach to the rocky island is a tombolo.

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.

Media Attributions

- Figure 17.0.1: Image by Todd Byrnes. Used with permission of Chesterman Beach B & B.

17.1 Waves

Waves form on the ocean and on 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 important parameters of a wave are the **wavelength** (the horizontal distance between two crests or two troughs), the **amplitude** (the vertical distance between a **trough** and a **crest**), and the wave velocity (the speed at which wave crests move across the water) (Figure 17.1.1).

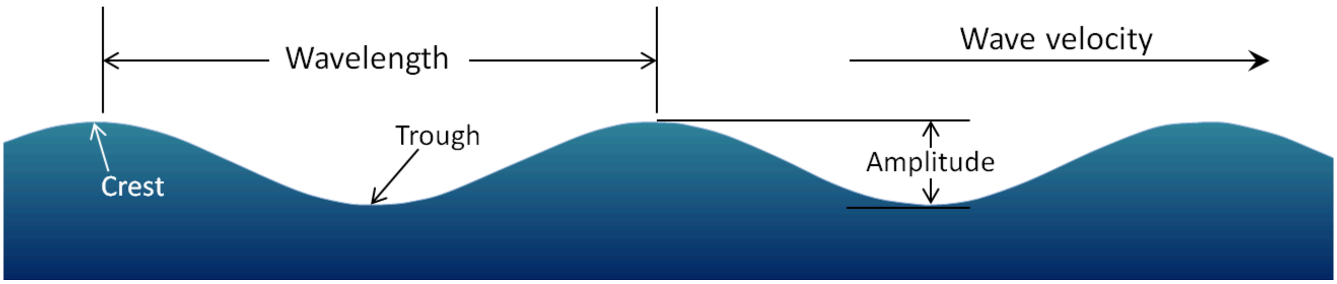

Figure 17.1.1 The parameters of water waves.

The typical sizes and speeds of waves in situations where they have had long enough to develop fully are summarized in Table 17.1. In a situation where the fetch is short (say 19 km on a lake) and the wind is only moderate (19 km/h), the waves will develop fully within 2 hours, but they will remain quite small (average amplitude about 27 cm, wavelength 8.5 m). On a large body of water (the ocean or a very large lake) with a fetch of 139 km and winds of 37 km/h, the waves will develop fully in 10 hours; the average amplitude will be around 1.5 m and average wavelength around 34 m. In the open ocean, with strong winds (92 km/h) that blow for at least 69 hours, the waves will average nearly 15 m high and their wavelengths will be over 200 m. Small waves (amplitudes under a metre) tend to have relatively shallow slopes (amplitude is 3% to 4% of wavelength), while larger waves (amplitudes over 10 m) have much steeper slopes (amplitude is 6% to 7% of wavelength). In other words, not only are large waves bigger than small ones, they are also generally more than twice as steep, and therefore many times more impressive—and potentially dangerous. It is important to recognize, however, that amplitudes decrease with distance from the area where the waves were generated. Waves on our coast that are generated by a storm near Japan will have similar wavelengths but lower amplitudes than those generated by a comparable storm just offshore.

Table 17.1 The parameters of wind waves in situations where the wind blows in roughly the same direction for long enough for the waves to develop fully. The duration times listed are the minimum required for the waves to develop fully.[1]

[Skip Table]

Wind Speed (kilometres per hour)	Fetch (kilometres)	Duration (hours)	Amplitude (metres)	Wavelength (metres)	Wave Period (seconds)	Wave Velocity (metres per second)	Wave Velocity (kilometres per hour)
19	19	2	0.27	8.5	3.0	2.8	10.2
37	139	10	1.5	33.8	5.7	5.9	19.5
56	518	23	4.1	76.5	8.6	8.9	32.0
74	1,313	42	8.5	136	11.4	11.9	42.9
92	2,627	69	14.8	212	14.3	14.8	53.4

Exercise 17.1 Wave height versus length

This table shows the typical amplitudes and wavelengths of waves generated under different wind conditions. The steepness of a wave can be determined from these numbers and is related to the ratio: amplitude/wavelength.

1. Calculate these ratios for the waves shown. The first one is done for you.
2. How would these ratios change with increasing distance from the wind that produced the waves?

Calculate the wave ratios.

Amplitude (metres)	Wavelength (metres)	Ratio (amplitude divided by wavelength)
0.27	8.5	0.03
1.5	33.8	
4.1	76.5	
8.5	136	
14.8	212	

See Appendix 3 for Exercise 17.1 answers.

Relatively small waves move at up to about 10 km/h and arrive on a shore about once every 3 seconds.

1. Table by Steven Earle from data at: http://en.wikipedia.org/wiki/Wind_wave]

Very large waves move about five times faster (over 50 km/h), but because their wavelengths are so much longer, they arrive less frequently—about once every 14 seconds.

As a wave moves across the surface of the water, the water itself mostly just 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 that is equal to the wave amplitude (Figure 17.1.2). 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. Wave motion is illustrated quite clearly on the [Wikipedia "Wind wave" site](). If you look carefully at that animation, and focus on the small white dots in the water, you should be able to see how the amount that they move decreases with depth.

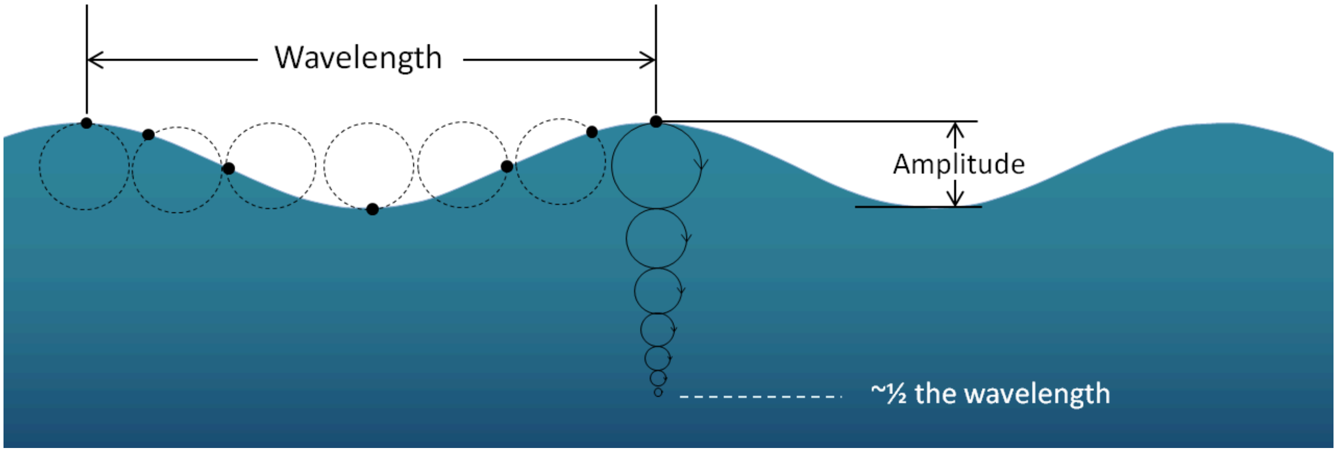

Figure 17.1.2 The orbital motion of a parcel of water (black dot) as a wave moves across the surface.

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 greater than 200 m, and the open ocean is several thousand metres deep, the wave base does not normally interact with the bottom of the ocean. However, as waves approach the much shallower water near the shore, they start to "feel" the bottom, and they are affected by that interaction (Figure 17.1.3). 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 (Figure 17.1.4).

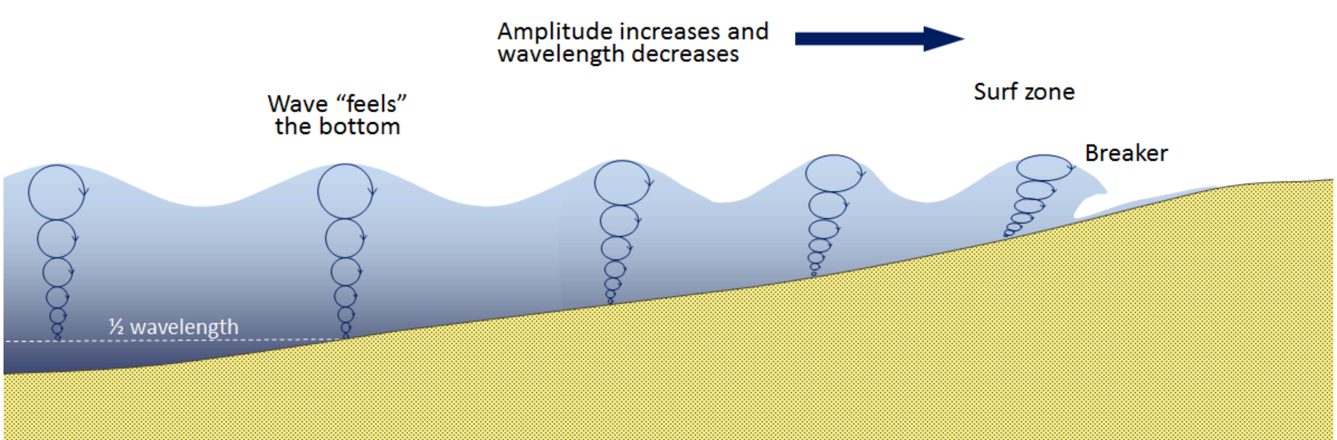

Figure 17.1.3 The effect of waves approaching a sandy shore.

Figure 17.1.4 Waves breaking on the shore at Greensand Beach, Hawaii (the sand is green because it is made up mostly of the mineral olivine eroded from the nearby volcanic rocks).

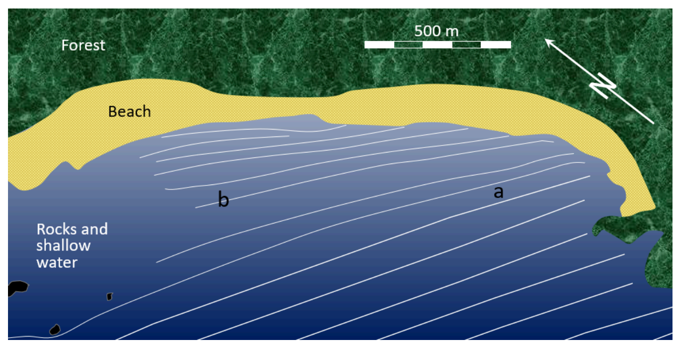

Figure 17.1.5 Waves approaching the shore of Long Beach in Pacific Rim National Park. As the waves (depicted by white lines) approach shore, they are refracted to become more parallel to the beach, and their wavelength decreases.

Waves normally 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. This process is illustrated in Figure 17.1.5, which is based on an aerial photograph showing actual waves approaching Long Beach on Vancouver Island. When the photo was taken, the waves (with crests shown as white lines in the diagram) were approaching at an angle of about 20° to the beach. The waves first reached shore at the southern end ("a" on the image). As they moved into shallow water they were slowed, and since the parts of the waves still in deep water ("b" on the image) were not slowed they were able catch up, and thus the waves became more parallel to the beach.

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 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** (the areas where waves are breaking) (Figure 17.1.6).

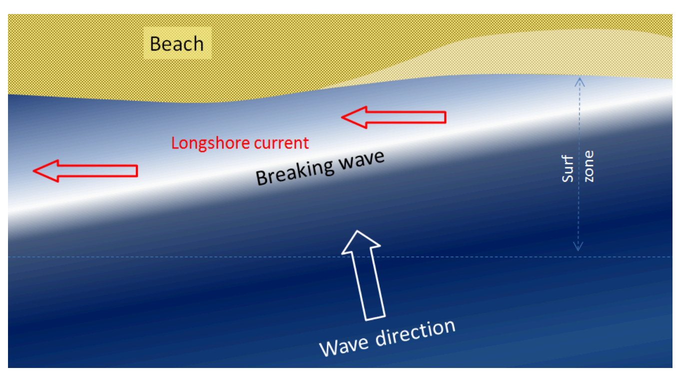

Figure 17.1.6 The generation of a longshore current by waves approaching the shore at an angle.

Exercise 17.2 Wave refraction

A series of waves (dashed lines) is approaching the coast on the map shown here.

The location of the depth contour that is equivalent to 1/2 of the wavelength is shown as a red dashed line.

Draw in the next several waves, showing how their patterns will change as they approach shallow water and the shore.

Show, with arrows, the direction of the resulting longshore current.

See Appendix 3 for Exercise 17.2 answers.

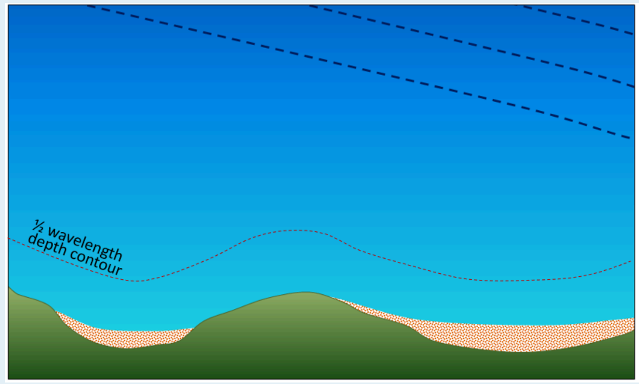

Figure 17.1.7

Another important 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 flows back down the beach, it moves straight down the slope of the beach (Figure 17.1.8). 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 then down the beach, particles of sediment are moved along the beach in a zigzag pattern.

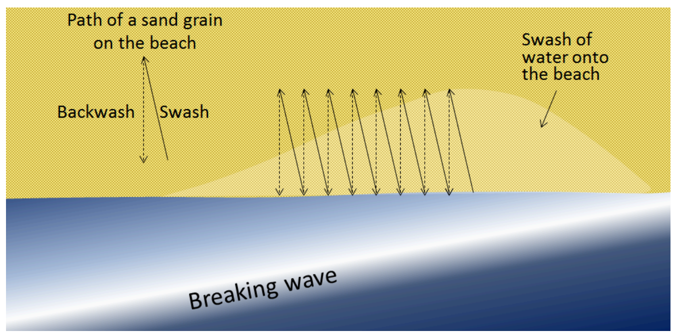

Figure 17.1.8 The movement of particles on a beach as a result of swash and backwash.

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 that we'll discuss in section 17.3.

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. As shown in Figure 17.1.9, rip currents flow straight out from the shore and are fed by the longshore currents. They die out quickly just outside the surf zone, but can be dangerous to swimmers who get caught in them. 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.

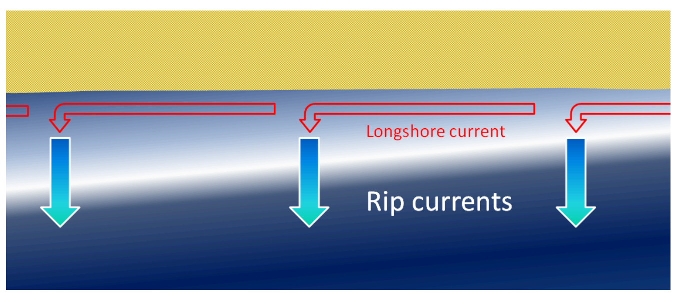

Figure 17.1.9 The formation of rip currents on a beach with strong surf.

Rip currents are visible in Figure 17.1.10, a beach at Tunquen in Chile near Valparaiso. As is evident from the photo, the rips correspond with embayments in the beach profile. Three of them are indicated with arrows, but it appears that there may be several others farther along the beach.

Figure 17.1.10 Rip currents on Tunquen Beach in central Chile.

Tides are related to very long-wavelength but low-amplitude waves on the ocean surface (and to a much lesser extent on very large lakes) that are caused by variations in the gravitational effects of the Sun and Moon. Tide amplitudes in shoreline areas vary quite dramatically from place to place. On the west coast of Canada, the tidal range is relatively high, in some areas as much as 6 m, while on most of the east coast the range is lower, typically around 2 m. A major exception is the Bay of Fundy between Nova Scotia and New Brunswick, where the daily range can be as great as 16 m. Anomalous tides like that are related to the shape and size of bays and inlets, which can significantly enhance the amplitude of the tidal surge. The Bay of Fundy has a natural oscillation cycle of 12.5 hours, and that matches the frequency of the rise and fall of the tides in the adjacent Atlantic Ocean. Ungava Bay, on Quebec's north coast, has a similarly high tidal range.

As the tides rise and fall they push and pull a large volume of water in and out of bays and inlets and around islands. They do not have as significant an impact on coastal erosion and deposition as wind waves do, but they have an important influence on the formation of features within the intertidal zone, as we'll see in the following sections.

Media Attributions

17.2 Landforms and Coastal Erosion

Large waves crashing onto a shore bring a tremendous amount of energy that has a significant eroding effect. 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. In Figure 17.2.1, wave energy is represented by the red arrows. That energy is evenly spaced out in the deep water, but because of refraction, the energy of the waves—which moves perpendicular to the wave crests—is being focused on the **headlands** (Frank Island and Cox Point in this case). 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.

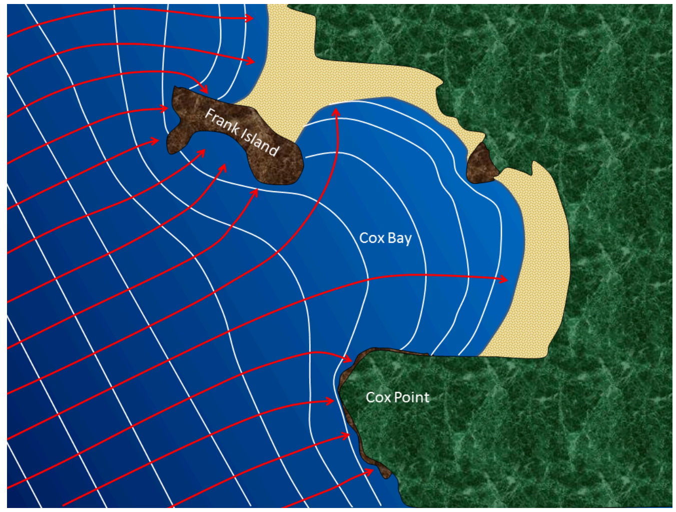

Figure 17.2.1 The approach of waves (white lines) in the Cox Bay area of Long Beach, Vancouver Island. The red arrows represent wave energy; most of that energy is focused on the headlands of Frank Island and Cox Point.

Wave erosion is greatest in the surf zone, where the wave base is impinging strongly on the sea floor 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** (or wave-cut terrace) (Figure 17.2.2). A wave-cut platform typically extends across the intertidal zone.

Figure 17.2.2 A wave-cut platform in bedded sedimentary rock on Gabriola Island, B.C. The wave-eroded surface is submerged at high tide.

Relatively resistant rock that does not get completely eroded during the formation of a wave-cut platform will remain behind to form a **stack**. An example from the Juan de Fuca Trail of southwestern Vancouver Island is shown in Figure 17.2.3. 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. Note that this is a somewhat unique situation. Most stacks do not show that nature of differential erosion.

Figure 17.2.3 A stack on the Juan de Fuca Trail section of the southwestern shore of Vancouver Island. The rock surrounding the stack is part of a wave-cut platform.

Arches and **sea caves** are related to stacks because they all form as a result of the erosion of relatively non-resistant rock. An arch in the Barachois River area of western Newfoundland is shown in Figure 17.2.4. This feature started out as a sea cave, and then, after being eroded from both sides, became an arch. During the winter of 2012/2013, the arch collapsed, leaving a small stack at the end of the point. If you look carefully at the upper photograph you can see that the hole that makes the arch developed within a layer of relatively soft and weak rock.

Figure 17.2.4 Top: An arch in tilted sedimentary rock at the mouth of the Barachois River, Newfoundland, July 2012. Bottom: The same location in June 2013. The arch has collapsed and a small stack remains.

Figure 17.2.5 summarizes the process of transformation of an irregular coast, initially produced by tectonic uplift, into a straightened coast with **sea cliffs** (wave-eroded escarpments) and the remnants of stacks, arches, and wave-cut platforms. The next stages of this process would be the continued landward erosion of the sea cliffs and the complete erosion of the stacks and wave-cut platforms in favour of a continuous nearly straight coast. That straight coast might be a sea cliff, or—if there is a sufficient and ongoing source of sand—a beach

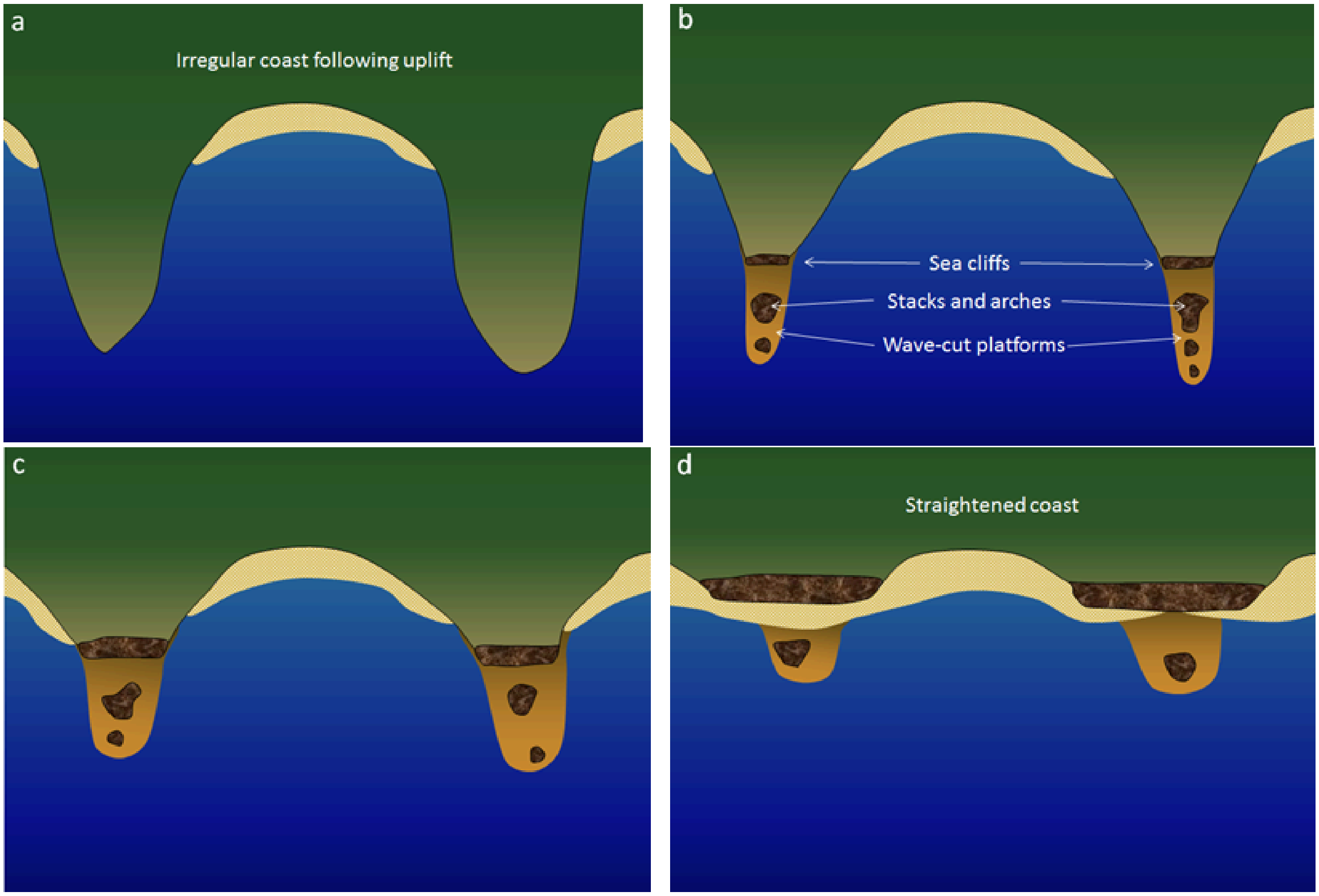

Figure 17.2.5 Evolution of a straightened coast through the erosion to stacks and arches, sea cliffs, and wave-cut platforms.

Media Attributions

- Figures 17.2.1, 17.2.2, 17.2.3, 17.2.5: © Steven Earle. CC BY.
- Figure 17.2.4: Image by Dr. David Murphy. Used with permission.

17.3 Landforms and 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. But on almost all coasts, both deposition and erosion are happening to varying degrees most of the time, although in different places. This is clearly evident in the Tofino area of Vancouver Island (Figure 17.0.1), where erosion is the predominant process on the rocky headlands, while depositional processes predominate within the bays. On deposition-dominant coasts, the coastal sediments are still being eroded from some areas and deposited in others.

A key factor in determining if a 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. Another important factor is the supply of sediments. Unless there is a continuous supply of sandy and coarser sediment to a coast it will not be a depositional coast.

On coasts that are 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 at Vancouver. There are no large rivers bringing 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 comes from the erosion of the rocks on the headlands.

The components of a typical beach are shown in Figure 17.3.1. On a sandy marine beach, the **beach face** is the area between the low and high tide levels. A **berm** is a flatter region beyond the reach of high tides; this area stays dry except during large storms.

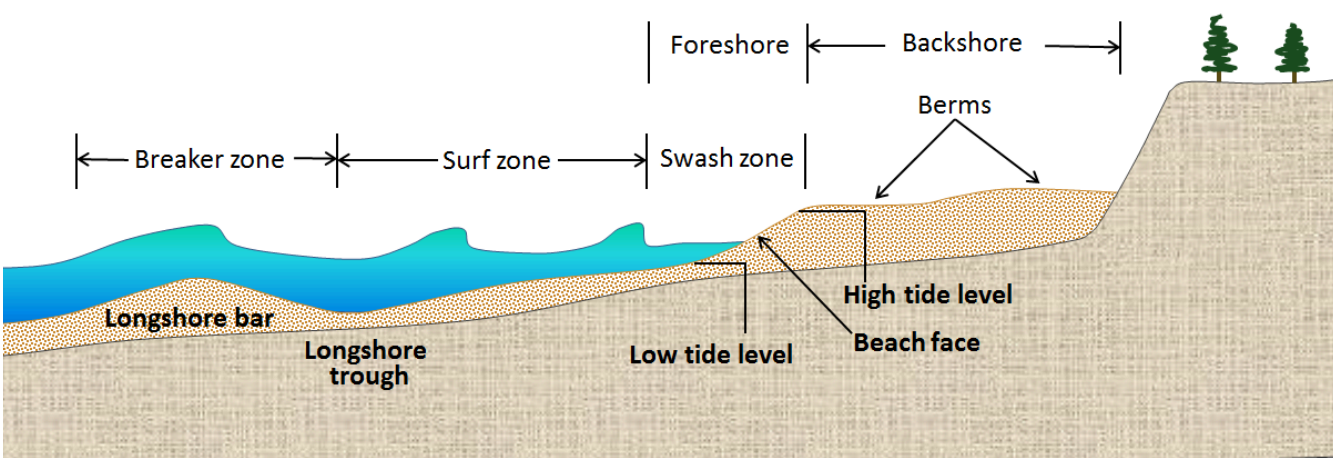

Figure 17.3.1 The components of a sandy marine beach. [Image Description]

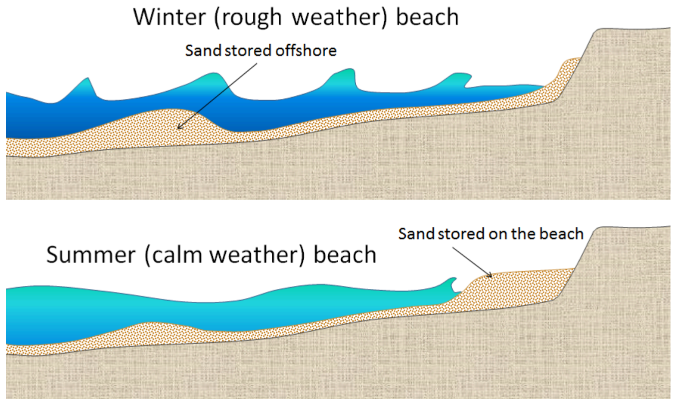

Figure 17.3.2 The differences between summer and winter on beaches in areas where the winter conditions are rougher and waves have a shorter wavelength but higher energy. In winter, sand from the beach is stored offshore.

Most beaches go through a seasonal cycle because conditions change from summer to winter. In summer, sea conditions are relatively 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 shown in Figure 17.3.2, the heavy seas of winter gradually erode sand from beaches, moving it to an underwater sandbar offshore from the beach. The gentler waves of summer gradually push this sand back toward the shore, creating a wider and flatter beach.

The evolution of sandy depositional features on sea coasts 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. A **spit**, for example is an elongated sandy deposit that extends out into open water in the direction of a longshore current. A good example is Goose Spit at Comox on Vancouver Island (Figure 17.3.3). At this location, the longshore current typically flows toward the southwest, and the sand eroded from a 60 m high cliff of Pleistocene glaciofluvial Quadra Sand is pushed in that direction and then out into Comox Harbour.

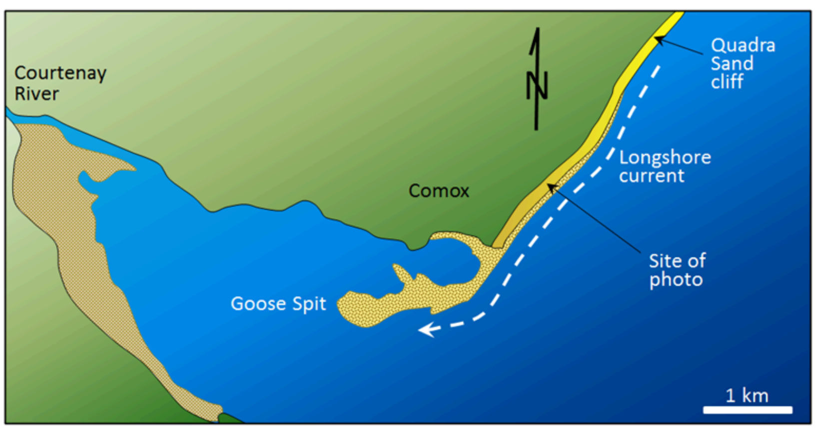

Figure 17.3.3 The formation of Goose Spit at Comox on Vancouver Island. The sand that makes up Goose Spit is derived from the erosion of Pleistocene Quadra Sand (a thick glaciofluvial sand deposit, as illustrated in the photo on the right).

The Quadra Sand at Comox is visible in Figure 17.3.4. There are numerous homes built at the top of the cliff, and the property owners have gone to considerable expense to reinforce the base of the cliff with large angular rocks (**rip-rap**) and concrete barriers so as to limit further erosion of their properties. One result of this will be to starve Goose Spit of sediments and eventually contribute to its erosion. Of course the rocks and concrete barriers are only temporary; they will be eroded by strong winter storms over the next few decades and the Quadra Sand will once again contribute to the maintenance of Goose Spit.

Figure 17.3.4 The Quadra Sand cliff at Comox, and the extensive concrete and rip-rap barrier that has been constructed to reduce erosion. Note that the waves (dashed lines) are approaching the shore at an angle, contributing to the longshore drift.

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 has to get out, it is rare that a baymouth bar will completely close the entrance to a bay. In areas where there is sufficient sediment being transported, and there are near-shore islands, a **tombolo** may form (Figure 17.3.5).

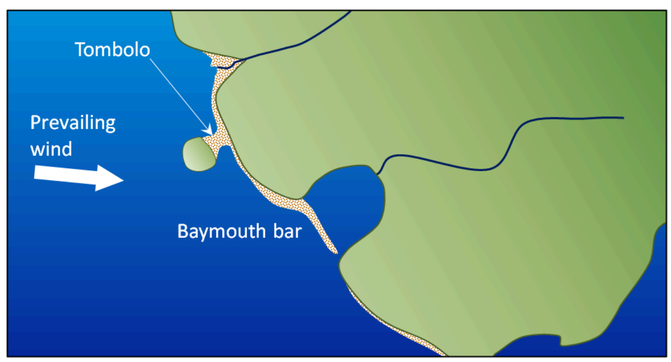

Figure 17.3.5 A depiction of a baymouth bar and a tombolo.

Tombolos are common around the southern part of the coast of British Columbia, where islands are abundant, and they typically form where there is a wave shadow behind a nearshore island (Figure 17.3.6). 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. There is a good example of a tombolo in Figure 17.0.1, and another in Figure 17.3.7.

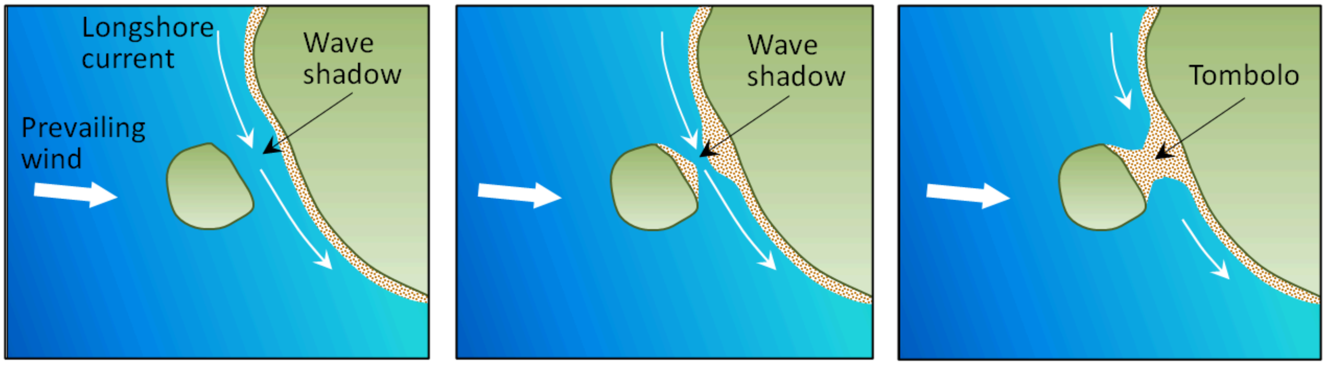

Figure 17.3.6 The process of formation of a tombolo in a wave shadow behind a nearshore island.

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 kilometres away from the mainland. They are common along the U.S. Gulf Coast from Texas to Florida, and along the U.S. Atlantic Coast from Florida to Massachusetts (Figure 17.3.8). North of Boston, the coast becomes rocky, partly because that area has been affected by post-glacial crustal rebound.

Figure 17.3.7 A stack (with a wave-cut platform) connected to the mainland by a tombolo, Gabriola Island, B.C.

Figure 17.3.8 Assateague Island on the Maryland coast, U.S. This barrier island is about 60 km long and only 1 km to 2 km wide. The open Atlantic Ocean is to the right and the lagoon is to the left. This part of Assateague Island has recently been eroded by a tropical storm, which pushed massive amounts of sand into the lagoon.

Exercise 17.3 Beach forms

On the map, sketch where you would expect the following to form:

- A spit
- A baymouth bar
- A tombolo

What conditions might lead to the formation of barrier islands in this area?

See Appendix 3 for Exercise 17.3 answers.

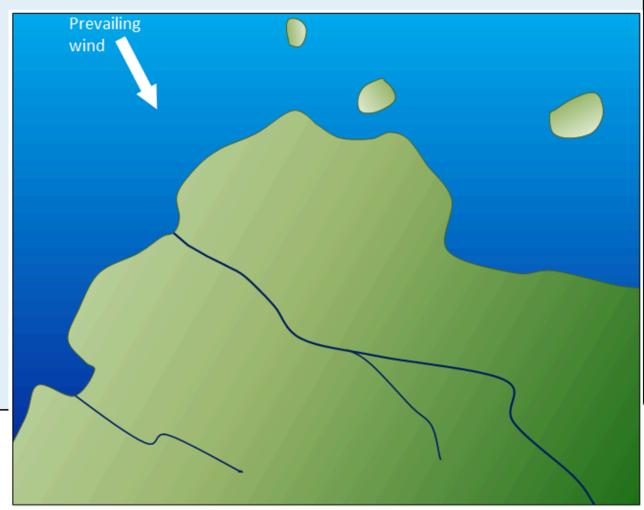

Figure 17.3.9

Some coasts in tropical regions (between 30° S and 30° N) are characterized by carbonate **reefs**. Reefs form in relatively shallow marine water within a few hundred to a few thousand metres of shore in areas where the water is clear because there is little or no input of clastic sediments from streams, and marine organisms such as corals, algae, and shelled organisms can thrive. The associated biological processes are enhanced where upwelling currents bring chemical nutrients from deeper water (but not so deep that the water is cooler than about 25°C) (Figure 17.3.10). Sediments that form in the **back reef** (shore side) and **fore reef** (ocean side) are typically dominated by carbonate fragments eroded from the reef and from organisms that thrive in the back-reef area that is protected from wave energy by the reef.

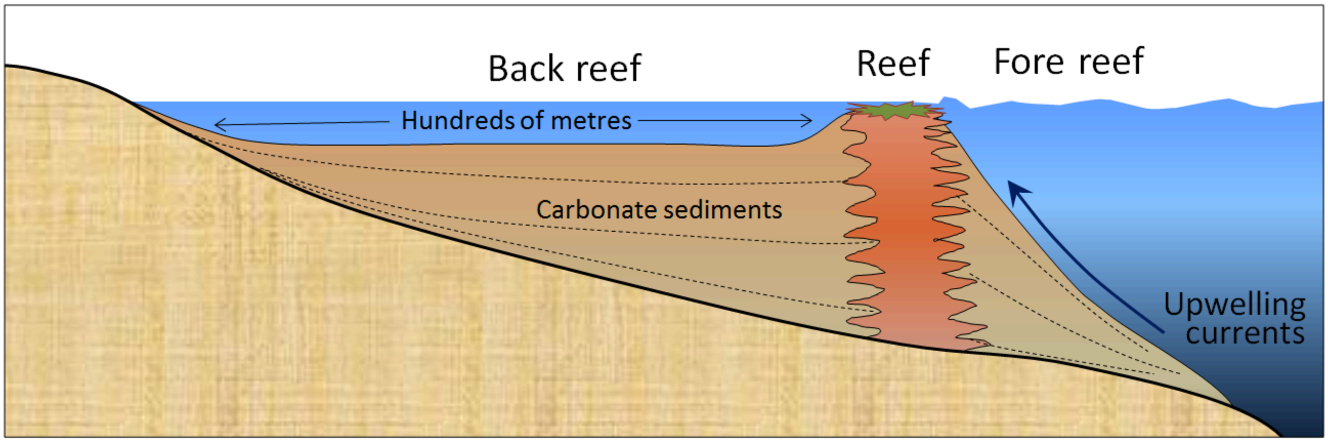

Figure 17.3.10 Cross-section through a typical barrier or fringing reef.

Image descriptions

Figure 17.3.1 image description: A berm, the part of a beach that is beyond the reach of high tide, is part of the backshore. The beach face, the part of the beach between low tide and high tide level, includes the swash zone and the foreshore. Beyond the swash zone is the surf zone and beyond that is the breaker zone. [Return to Figure 17.3.1]

Media Attributions

17.4 Sea-Level Change

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

Eustatic sea-level changes are global sea-level changes related either to changes in the volume of glacial ice on land or to changes in the shape of the sea floor caused by plate tectonic processes. For example, changes in the rate of mid-ocean spreading will change the shape of the sea floor near the ridges, and this affects sea level.

Over the past 20,000 years, there has been approximately 125 m of eustatic sea-level rise due to glacial melting. Most of that took place between 15,000 and 7,500 years ago during the major melting phase of the North American and Eurasian Ice Sheets (Figure 17.4.1). During that time the average rate of sea level rise was approximately 14 mm/y. At around 7,500 years ago, the rate of glacial melting and sea-level rise decreased dramatically. The average rate over the past 6000 years has been 0.5 mm/y. Anthropogenic climate change led to accelerating sea-level rise starting around 1870. Since then the average rate has been about 1.1 mm/y, but it has been gradually increasing. The current rate is over 3 mm/y.

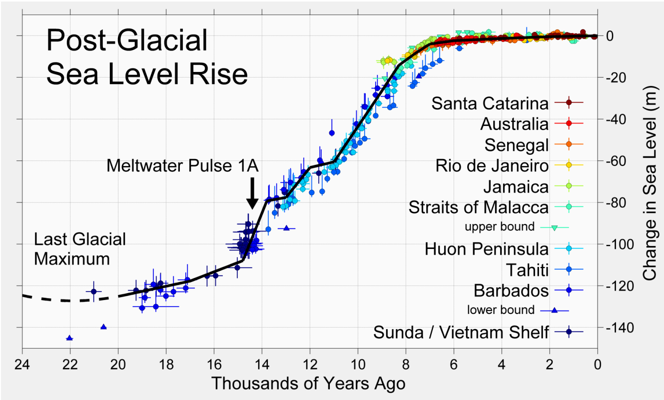

Figure 17.4.1 Eustatic sea-level curve for the past 24 ka (sea-level rise resulting from the melting of glacial ice). Sea-level rise is global; the locations listed in the caption are the places where data were acquired to create this diagram.

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 metres 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 B.C. In other words, although 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.

There is evidence of isostatic rebound along the southwest coast of Vancouver Island, where a number of streams enter the ocean as 5 m high waterfalls, as shown in Figure 17.4.2.

Tectonic sea-level changes are local changes caused by tectonic processes. The subduction of the Juan de Fuca Plate beneath British Columbia, Washington, Oregon and northern California is creating tectonic uplift (about 1 mm/year) along the western edge of the continent, although much of this uplift is likely to be reversed when the next large subduction-zone earthquake strikes.

Figure 17.4.2 This stream is on the southwest coast of Vancouver Island near Sooke. Like many other streams along this coast, it used to flow directly into the ocean, but the land has been uplifted by post-glacial isostatic rebound.

Figure 17.4.3 Howe Sound, north of Vancouver, is a fjord filling a former glacial valley

Coastlines in areas where there has been net sea-level rise in the geologically recent past are commonly characterized by estuaries and fjords. Howe Sound, north of Vancouver, is an example of a fjord (Figure 17.4.3). This valley was filled with ice during the last glaciation, and there has been a net rise in sea level here since that time. Coastlines in areas where there has been net sea-level drop in the geologically recent past are characterized by uplifted wave-cut platforms (or stream valleys as shown in Figure 17.4.2). Uplifted beach lines are another product of relative sea-level drop, although these are difficult to recognize in areas with vigorous vegetation. They are relatively common in Canada's far north.

Exercise 17.4 A holocene uplifted shore

The blue-grey sediments in the photo contain marine fossils of early Holocene age (~12,500 years ago) situated at about 60 m above sea level on Gabriola Island, BC. Explain how eustatic and isostatic sea-level change processes might have contributed to the existence of these materials at this elevation.

Figure 17.4.4 Early Holocene marine sediments at 60 m elevation on Gabriola Island, B.C.

See Appendix 3 for Exercise 17.4 answers.

Media Attributions

- Figures 17.4.1, 17.4.3, 17.4.4: © Steven Earle. CC BY.
- Figure 17.4.2: "Post-Glacial Sea Level" © Robert A. Rohde. CC BY-SA.

17.5 Human Interference with Shorelines

There are various modifications that we make in an attempt to influence shoreline processes for our own purposes. Sometimes these changes are effective, and may appear to be beneficial, although in most cases there are unintended negative consequences that we don't recognize until much later.

An example is at the beach near Comox (described above), which has been armoured with rip-rap and concrete blocks in an attempt to limit the natural erosion that is threatening the properties at the top of the cliff (Figure 17.3.4). As already noted, the unintended effect of this installation will be to starve Goose Spit of sediment. As long as the armour remains in place, which might be several decades, there is a significant risk that the spit will start to erode, which will affect many of the organisms that use that area as their habitat, and many of the people who go there for recreation.

Seawalls, like the one around Vancouver's Stanley Park (Figure 17.5.1), also help to limit erosion and can be very pleasant amenities for the public, but they have geological and ecological costs. When a shoreline is "hardened" in this way, important marine habitat is lost and sediment production is reduced, and that can affect beaches elsewhere. Seawalls also affect the behaviour of waves and longshore currents, sometimes with negative results.

Figure 17.5.1 The seawall at Stanley Park, Vancouver.

Another example is at Sunset Beach in Vancouver. As shown in Figure 17.5.2, a series of rip-rap **breakwaters** (structures parallel to the shore) were built in the 1990s and sand has accumulated behind them to form the beach. The breakwaters have acted as islands and the sand has been deposited in the low-energy water behind them, in the same way that a tombolo forms. This can be seen from a photograph taken from the Burrard Bridge in 2015 (Figure 17.5.3). The two benefits of this project are that a pleasant beach has been created, and some of the sediment that previously would have been moved into False Creek, and could have blocked its entrance, has been trapped in English Bay. The negative impacts are probably not well understood, but have likely involved loss of marine animal habitat.

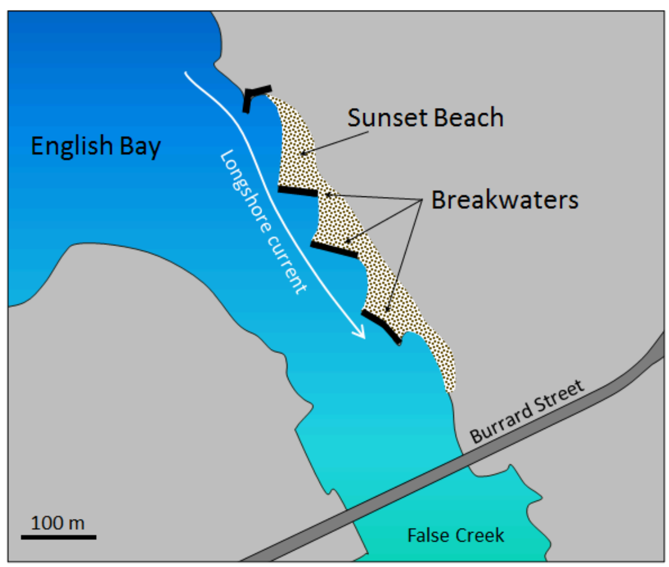

Figure 17.5.2 Map of the impact of breakwaters (or groynes) on beach formation at Sunset Beach, Vancouver.

Figure 17.5.3 Photograph of the impact of breakwaters on beach development at Sunset Beach, Vancouver.

Groynes (or groins in the U.S.) have an effect that is similar to that of breakwaters, although groynes are constructed perpendicular to the beach (Figure 17.5.4), and they trap sediment by slowing the longshore current.

Figure 17.5.4 A groyne at Crescent Beach, Surrey, B.C.

Most of the sediment that forms beaches along our coasts comes from rivers, so if we want to take care of 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 kilometres of the river's mouth (or more in some cases) are at risk of erosion.

Exercise 17.5 Crescent beach groynes

This diagram shows the same area illustrated in Figure 17.5.4 at Crescent Beach in Surrey, B.C. Based on information that you can find on the Internet about the function of groynes, determine which way the prevailing longshore current is moving at this location.

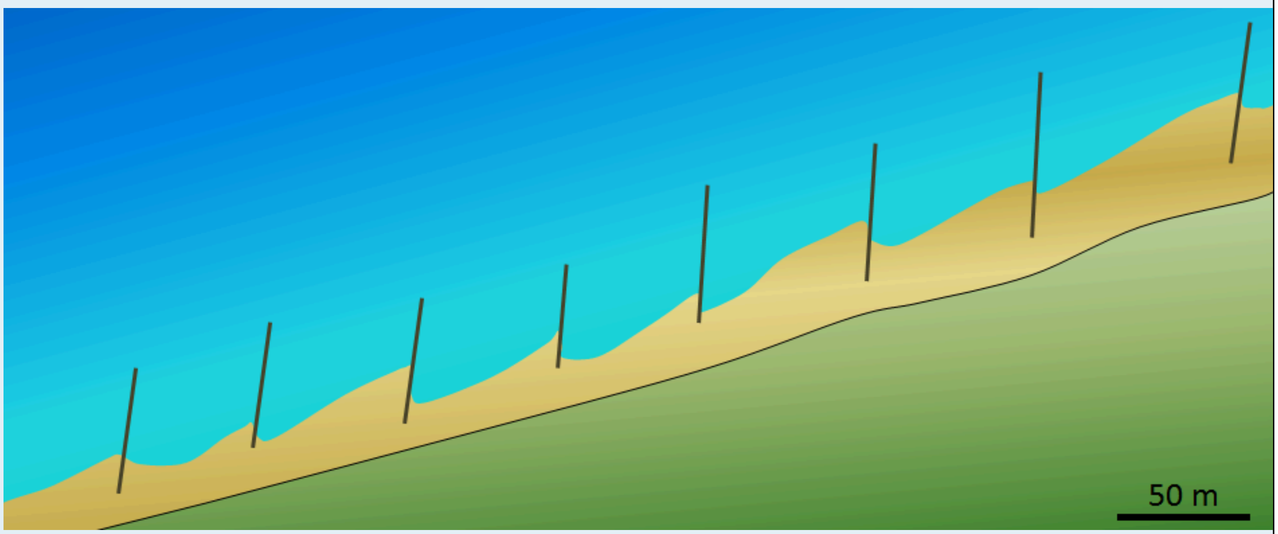

Figure 17.5.5 Beach and groyne locations at Crescent Beach, Surrey.

See Appendix 3 for Exercise 17.5 answers.

Media Attributions

- Figure 17.5.1: "Seawall2" by Bonanny. Public domain.
- Figure 17.5.2: © Steven Earle. CC BY.
- Figure 17.5.3: "Sunset Beach" © Isaac Earle. CC BY.
- Figure 17.5.4: "Cresbeach groyne" © Arnold C. CC BY.
- Figure 17.5.5: © Steven Earle. CC BY.

Summary

The topics covered in this chapter can be summarized as follows:

Section	Summary
17.1 Waves	Waves form when wind blows over water. The size of the waves depends on the wind speed, the area over which it is blowing, and time. The important parameters of a wave are its amplitude, wavelength, and speed. The water beneath a wave is disturbed to a depth of one-half the wavelength, and a wave is slowed when it approaches shallow water. A longshore current develops where waves approach the shore at an angle, and swash and backwash on a beach move sediment along the shore. The combined effect of these two processes is sediment transport by longshore drift.
17.2 Landforms and Coastal Erosion	Coasts that have experienced uplift within the past few million years tend to have irregular shapes and are dominated by erosional processes. Wave paths are bent where the coast is irregular and wave energy is focused on headlands. Rocky headlands are eroded into sea caves, arches, stacks, and sea cliffs, and the areas around these features are eroded into wave-cut platforms. Over the long term (millions of years), irregular coasts are straightened.
17.3 Landforms and Coastal Deposition	Coasts that have not been uplifted for tens of millions of years tend to be relatively straight, and are dominated by depositional features, although deposition is also important on irregular coasts. Waves and longshore drift are important in controlling the formation of beaches, as well as spits, tombolos, baymouth bars, and barrier islands. Beaches can be divided into zones, such as foreshore and backshore, and beach shapes typically change from season to season. Carbonate reefs and carbonate sediments form in tropical regions where there is little input of clastic sediments.
17.4 Sea-Level Change	The relative levels of the land and sea have significant implications for coastal processes and landforms, and they have been constantly changing over geological time. Eustatic sea-level changes are global in effect, and are typically related to glacial ice formation or melting. Isostatic sea-level changes are local effects caused by uplift or subsidence of continental crust, typically because of the gain or loss of glacial ice. Tectonic sea-level changes are related to plate interactions. Net sea-level rise leads to development of estuaries and fjords, while net sea-level drop creates uplifted marine terraces and beaches.
17.5 Human Interference with Shorelines	Humans have a strong urge to alter coasts for their own convenience by building seawalls, breakwaters, groynes, and other barriers. Although these types of features may have economic and other benefits, they can have both geological and ecological implications that must be considered.

Questions for Review

See Appendix 2 for answers to Review questions.

1. What factors control the size of waves?
2. Referring to Table 17.1, approximately what size of waves (amplitude and wavelength) would you expect with a 65 km/h wind blowing for 40 hours over 1,000 km of sea?
3. If the average wavelength of a series of waves is 100 m, at what depth of water will the waves start to feel the bottom, and how will that change their behaviour?
4. What is the difference between a longshore current and longshore drift?
5. On Figure A the waves (dashed blue lines) are approaching an irregular coast. The red arrows represent the energy of those waves, and one has been extended to show where that energy would hit the shore. Extend the other “energy lines” in a similar way, and comment on how this relates to erosion of this coastline.
6. Explain the origins of a wave-cut platform.
7. How do we define the limits of the beach face, and what are some other terms used to describe this zone?
8. A spit is really just a beach that is only attached to the shore at one end. What conditions are necessary for the formation of a spit?
9. Barrier islands are common along the Atlantic coast of the U.S. as far north as Massachusetts. Why are there almost none in the northeastern U.S. or along the coasts of New Brunswick, Nova Scotia, and Newfoundland?

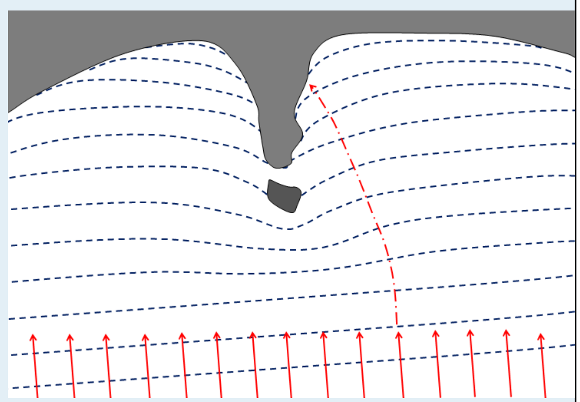

Figure A

10. Figure B represents an island on the central coast of B.C. that has experienced 140 m of isostatic rebound since deglaciation, and has also been affected by the global eustatic sea-level rise over the same period. The dashed line marks sea level during glaciation. How much higher or lower should that line be now?

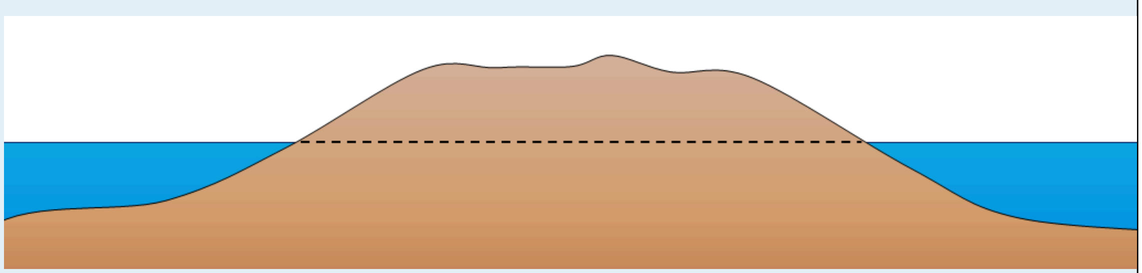

Figure B

11. If a dam were to be built on the Fraser River near Hope, what would be the long-term implications for beaches in the Vancouver area? Explain why.

Media Attributions

- Figure A, B: © Steven Earle. CC BY.