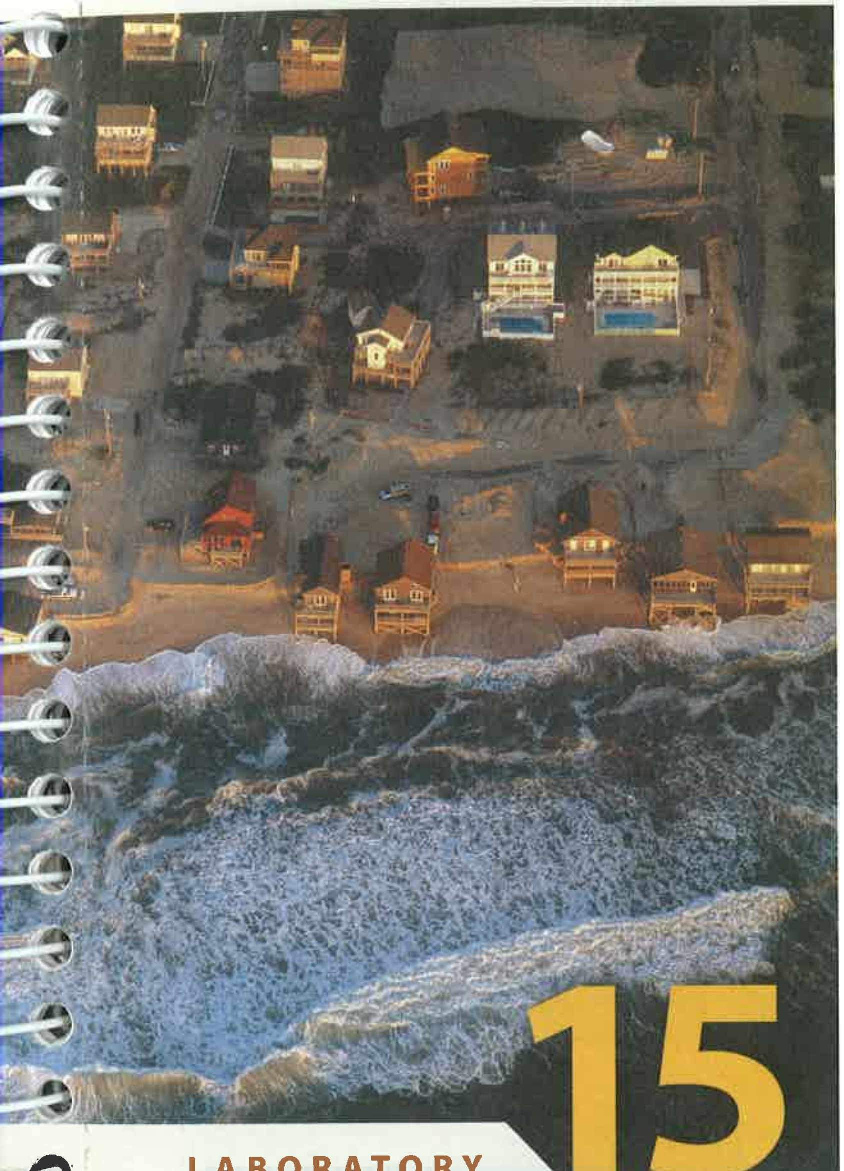


LABORATORY 15

Coastal Processes, Landforms, Hazards, and Risks

CONTRIBUTING AUTHORS

James G. Titus • *U.S. Environmental Protection Agency*

Donald W. Watson • *Slippery Rock University*

Storm waves are eroding sand from this Hatteras, North Carolina beach. Homeowners risk the loss of their properties when severe storms occur. (Photo by Michael Collier)

BIG IDEAS

A coastline is the boundary between land (geosphere) and the ocean or a lake (hydrosphere), but it is also affected by the atmosphere, organisms (biosphere, including humans), and sometimes glaciers (cryosphere). The shapes of coastal landforms depends on how the land is affected by the other spheres. Specific factors like waves, erosion, sediment supply, storms, and sea-level changes, are particularly effective in shaping coastal landforms and may pose hazards to humans or their property. Therefore, artificial structures are used to manage shorelines and protect coastal properties.

FOCUS YOUR INQUIRY

THINK About It | What factors affect the shape and position of shorelines?

THINK About It | How successful are efforts to protect shorelines from erosion by building artificial structures?

THINK About It | How will rising sea levels affect communities along shorelines?

Introduction

When viewed from an airplane or satellite, coastlines appear to be very simple—the obvious linear boundaries between land and the ocean or a lake. But at ground level, one cannot help but notice that coastlines are dynamic systems characterized by constant change. There is constant interaction among not only land (geosphere) and water (hydrosphere), but also the atmosphere, organisms (biosphere), and sometimes ice (cryosphere). Wind is blowing, water is flowing, rocks are being eroded, sediment is moving about, and landscapes are being shaped. Organisms, including humans, are abundant. The United Nations Environment Programme (UNEP) has found that more than half of the world's population lives within 60 km of the ocean, and three-quarters of all large cities are located on the coast. There, humans find many resources along copastlines, but they also face hazards associated with living at the dynamic interface of many spheres.

ACTIVITY 15.1 Coastline Inquiry

THINK About It **What factors affect the shape and position of shorelines?**

OBJECTIVE Compare and contrast photographs of coastlines and determine what factors primarily affect them.

PROCEDURES

1. **Before you begin,** read the Introduction and Dynamic Natural Coastlines below. Also, this is **what you will need:**
   ____ Activity 15.1 Worksheet (p. 385) and pencil
2. **Complete the worksheet in a way that makes sense to you.**
3. **After you complete the worksheet,** be prepared to discuss your observations and classification with other geologists.

Dynamic Natural Shorelines

Some examples of shorelines are pictured in **FIGURE 15.1**. In each case, the land is acted upon by water, wind, organisms, and sometimes ice, in ways that vary in both intensity and time. For example, there is constant water and air motion, but their intensities vary throughout the day in relation to tides and the weather. At one part of the day or year, the **erosional processes** (those that remove sediment and cut into rock, reefs, and marshes) may be dominant over the **depositional processes** (those that cause sediment to accumulate and marshes or reefs to grow). At another part of the day or year, the depositional processes may be dominant over the erosional ones. Over longer periods of time, one or the other process (erosion or deposition) is generally dominant, so most coastlines are either receding (moving landward, eroding back) or advancing (building seaward).

Factors Affecting Coastlines

There are many specific factors that affect the shapes of coastal landforms and the overall positions of coastlines, but here are some of the most important factors:

- **What the land is made of** determines how much the agents of change must work on the land to shape it. The land may be hard rock, clay, sand, large loose rocks, or a combination of these. The land may also be "armored" with large boulders (called "rip rap") or rigid concrete structures added by humans.
- **Supply of sediment** carried to a specific location along a coastline by rivers, coastal currents, or people often determines whether the coastline is sandy or of bare rock and whether the position of the coastline is advancing or receding. A coastline cannot advance seaward if it lacks a supply of sediment to do so. Some sediment may be eroded from the land itself, as when waves undercut a cliff and rocks collapse into the water.
- **Waves** carry sediment onto beaches when they are gentle (*low energy waves*), but they remove sediment from beaches and erode the land when they are large and forceful (*high energy waves*). Particles moved by waves and blasted against rocky surfaces will cause abrasion (smoothing and wearing down of the rocky surfaces). The direction of the waves is a factor in what direction sediment is moved and what parts of a coastline are eroded the most.
- **Wind** interacts with the surface of the water to generate the waves and blows beach sand into dune forms on the adjacent land.
- **Currents** running along the coastline (*longshore currents*), in streams reaching the coastline (*stream currents on deltas*), and back-and-forth through coastal environments (*tidal currents*) move sediment about and redeposit it on beaches, sand bars and spits, and tidal flats.
- **Storms** are highly energized systems, so they are one of the main factors that determines the shape of coastal landforms. A single storm, like a hurricane, can significantly erode one part of a coastline and deposit a large volume of sediment on another part of the coastline.
- **Organisms (including humans)** modify their environment. Corals construct reefs that armor the coastline against erosion. Marsh plants and mangroves trap and bind sediment with their roots and absorb the energy of storms. Humans use a variety of methods to preserve and build up coastlines, but they also destroy marshes and reefs and otherwise degrade elements of the coastline.

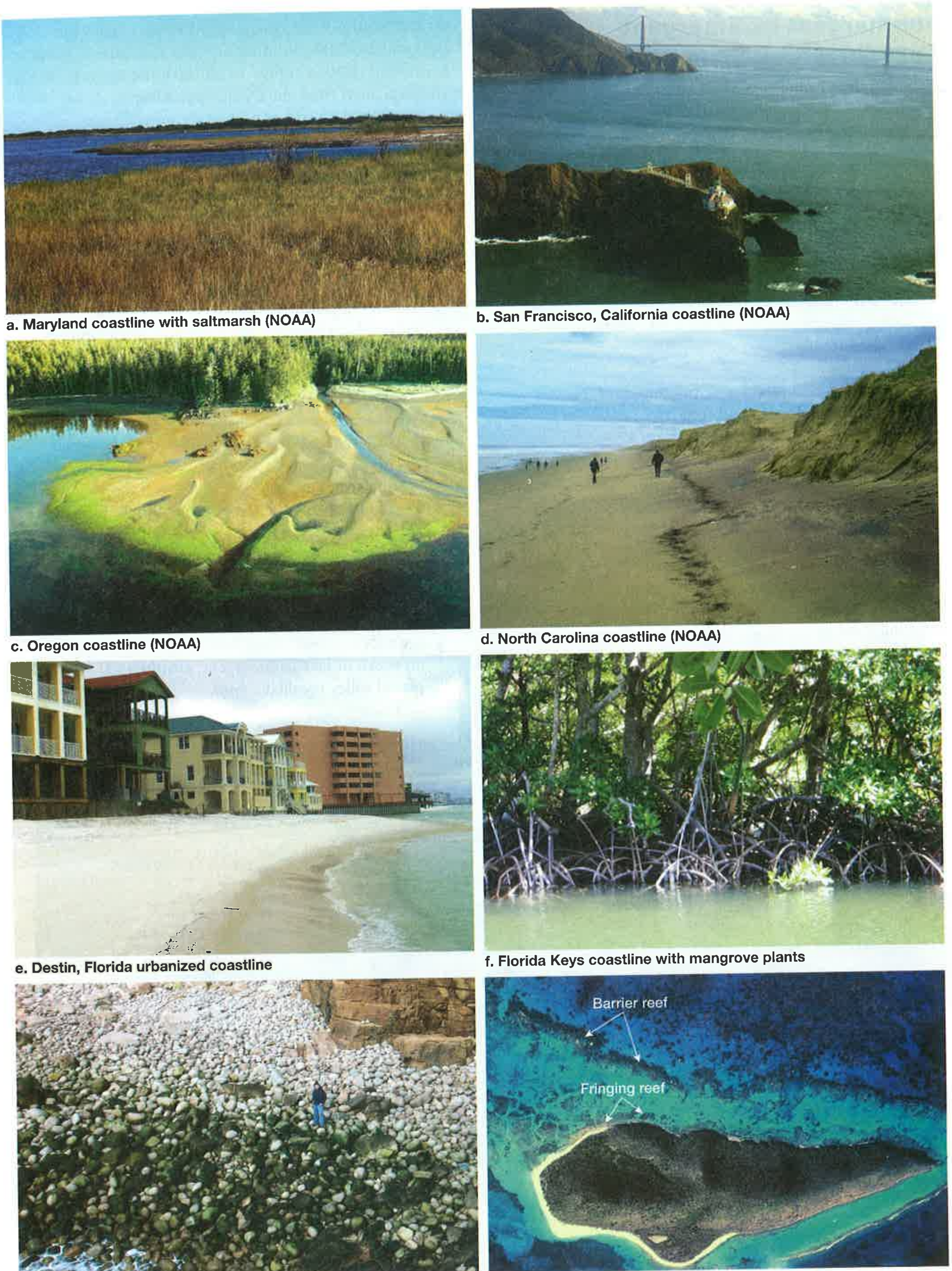
ACTIVITY 15.2 Introduction to Shorelines

THINK About It **What factors affect the shape and position of shorelines?**

OBJECTIVE Identify and interpret natural shoreline landforms and distinguish between emergent and submergent shorelines.

PROCEDURES

1. **Before you begin,** read Submergent vs. Emergent Coastlines below. Also, this is **what you will need:**
   ___ ruler, calculator
   ___ Activity 15.2 Worksheets (pp. 386–387) and pencil
2. **Then follow your instructor's directions** for completing the worksheets.



a. Maryland coastline with saltmarsh (NOAA)

b. San Francisco, California coastline (NOAA)

c. Oregon coastline (NOAA)

d. North Carolina coastline (NOAA)

e. Destin, Florida urbanized coastline

f. Florida Keys coastline with mangrove plants

g. Maine coastline (NOAA photo by Albert E. Theberge)

h. Caribbean island coastline with reefs (NOAA)

FIGURE 15.1 Photographs of eight different coastlines.

Submergent vs. Emergent Coastlines

Over decades of time, geologists characterize coastlines as submergent (retrogradational) or emergent (progradational): in one of two ways:

- A **submergent coastline**—is one that is being flooded, eroded back, or is otherwise receding (moving landward, retrograding). This can occur on short timescales due to erosion by waves, but it also occurs over longer periods of time due to sea-level rise. The sea level may rise may be caused by the water level actually rising (global sea-level rise, called *transgression*) or by the land getting lower (called *subsidence*).
- An **emergent coastline**—is one that is advancing (moving out into the water, prograding). This can occur when sediment and reefs build up to sea level, and then build seaward. It can also occur when sea level actually falls globally (called *regression*) or when the seafloor rises (called *uplift*). Uplift can occur because the region is tectonically active. It can also occur where the crust and mantle are rebounding upward after an ice sheet melts from atop them.

Submergent coastlines may display some emergent features, and vice versa. For example, the Louisiana coastline is submergent, enough so that dikes and levees have been built in an attempt (that failed in Hurricane Katrina) to keep the ocean from flooding New Orleans. However, the leading edge of the Mississippi Delta (at the mouth of the Mississippi River) is emergent (progradational)—building out into the water. This is because of the vast supply of sediment being carried there and deposited from the Mississippi River.

FIGURES 15.2 and **15.3** illustrate some features of *emergent* and *submergent* shorelines that you will need to identify in **FIGURE 15.4**, **15.5**, and **15.6** Study these features and their definitions below.

- **Barrier island**—a long, narrow island that parallels the mainland coastline and is separated from the mainland by a lagoon, tidal flat, or salt marsh (submergent, **FIGURE 15.3**).
- **Beach**—a gently sloping deposit of sand or gravel along the edge of a shoreline. Wide beaches are associated with emergent coastlines (**FIGURE 15.2**) and narrow beaches are associated with submergent coastlines (**FIGURE 15.3**).
- **Washover fan**—a fan-shaped deposit of sand or gravel transported and deposited landward of the beach during a "washover" of the land or island during a storm or very high tide.
- **Berm crest**—the highest part of a beach; it separates the *foreshore* (seaward part of the shoreline) from the *backshore* (landward part of the shoreline). This can occur on either type of coastline but is best developed on emergent coastlines that do not experience washover events.
- **Estuary**—a river valley flooded by a rise in the level of an ocean or lake (submergent, **FIGURE 15.3**). A flooded glacial valley is called a *fjord*.

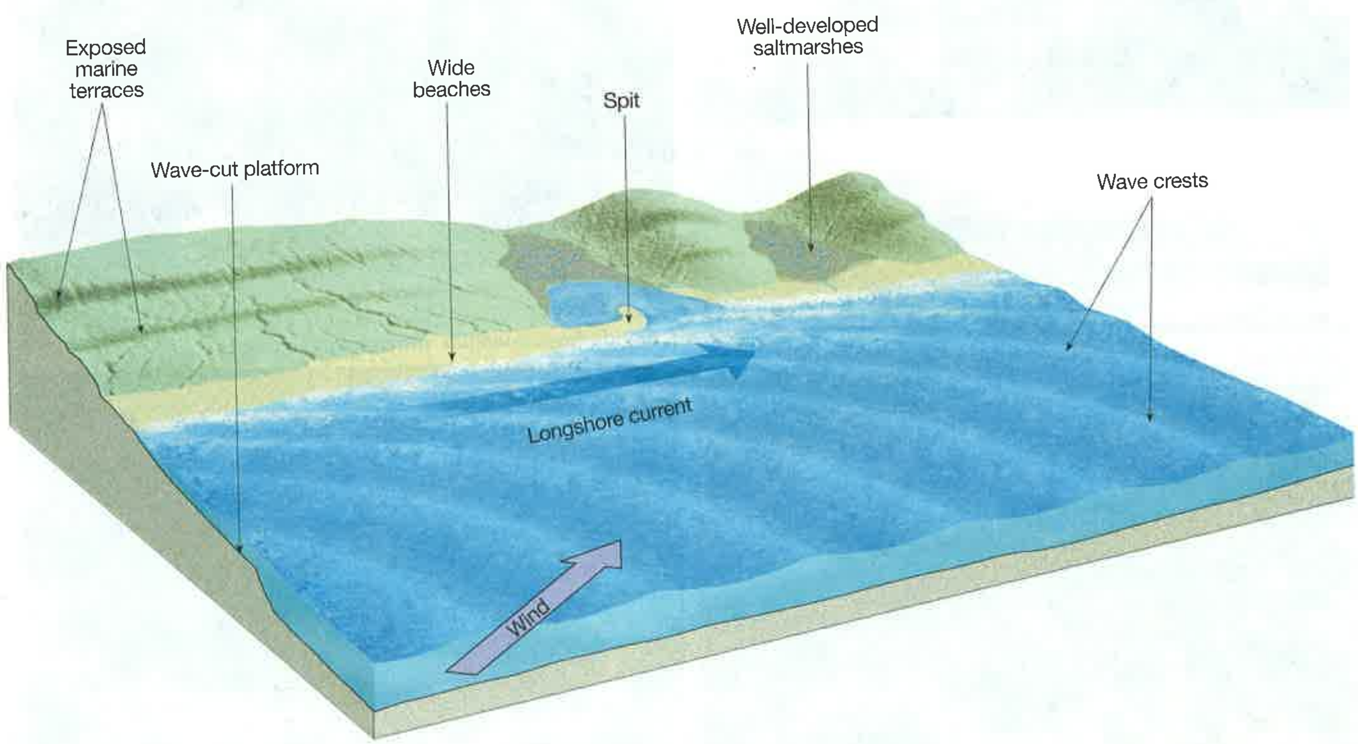


FIGURE 15.2 Emergent coastline features. An emergent coastline is caused by sea level lowering, the land rising, or both. Emergence causes tidal flats and coastal wetlands to expand, wave-cut terraces are exposed to view, deltas prograde at faster rates, and wide stable beaches develop.

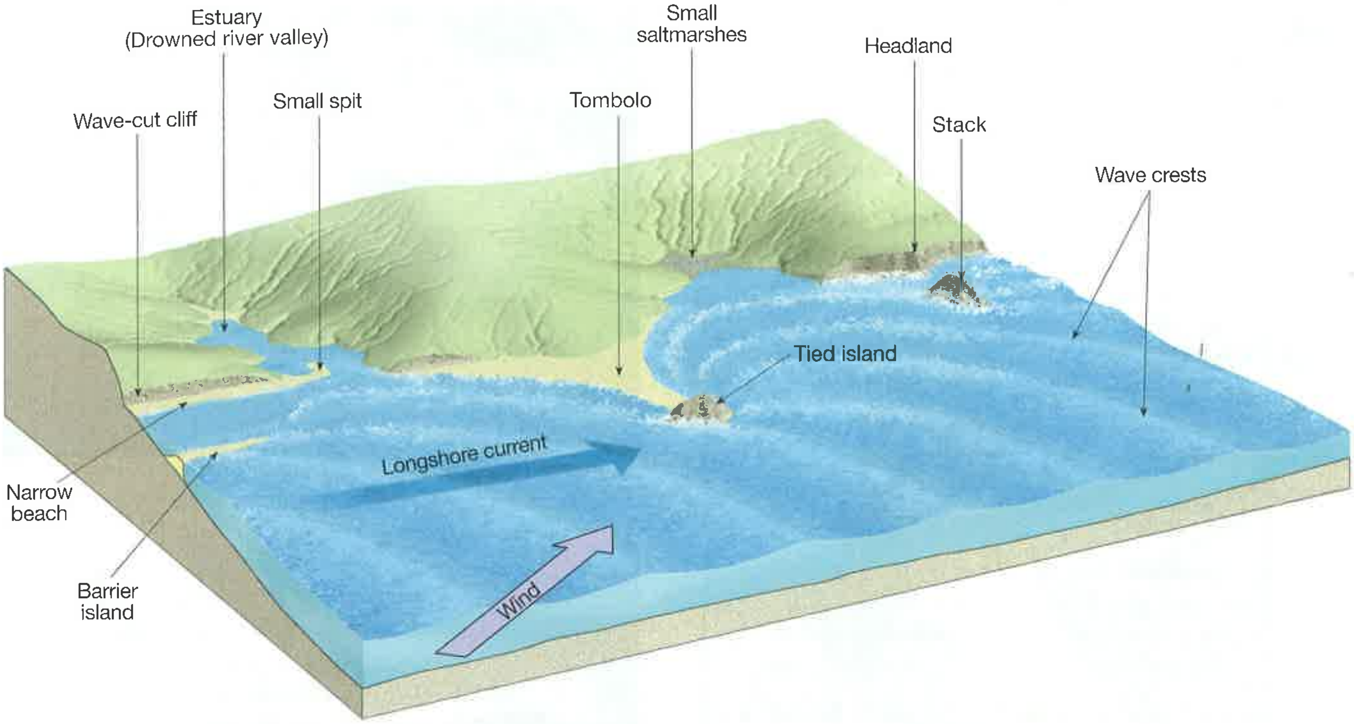


FIGURE 15.3 Submergent (drowning) coastline features. A submergent coastline is caused by sea level rising (transgression), sinking of the land, or both. As the land is flooded, the waves cut cliffs, valleys are flooded to form estuaries, wetlands are submerged, deep bays develop, beaches narrow, and islands are created.

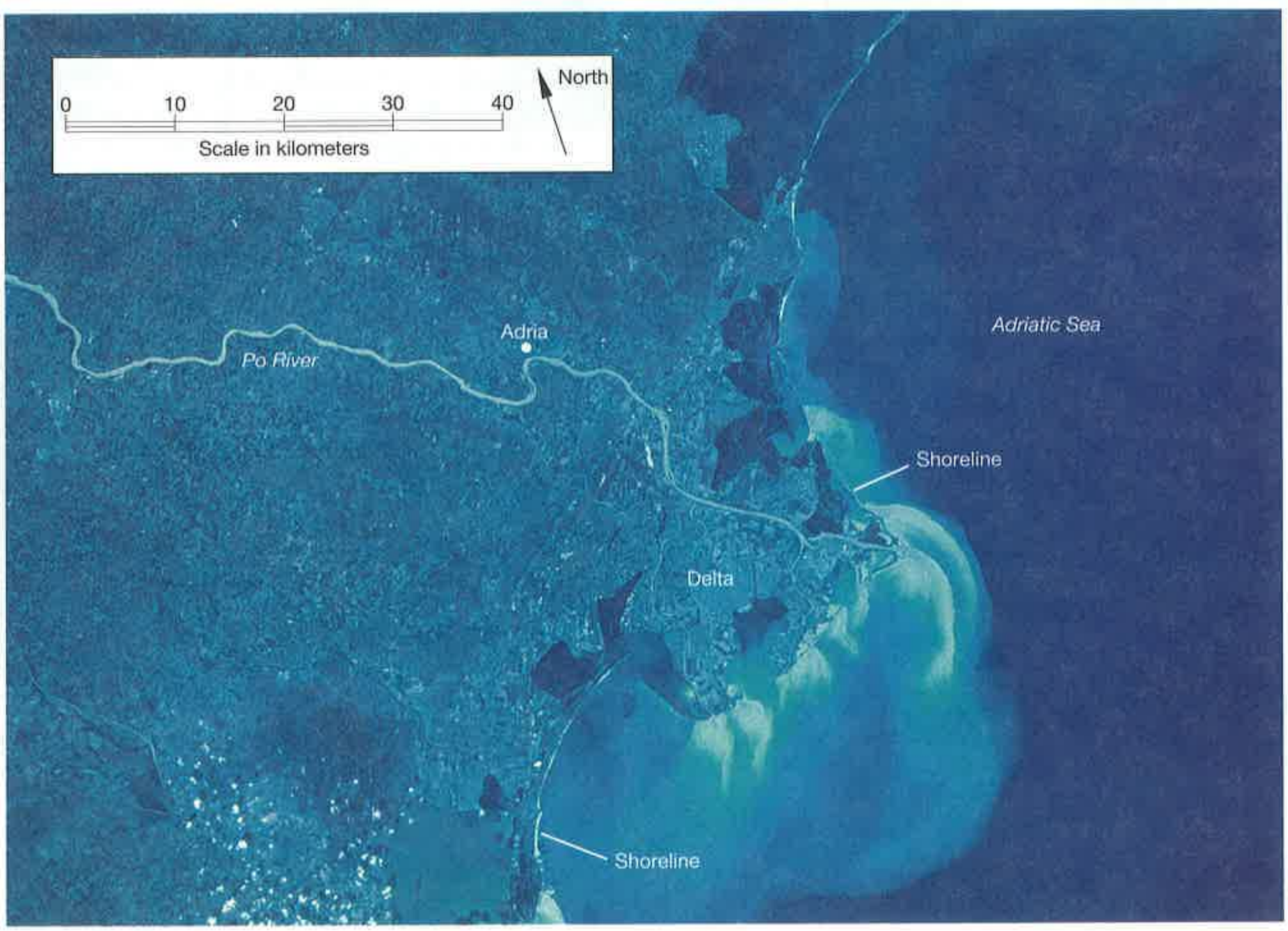


FIGURE 15.4 Space Shuttle photograph of the Po Delta region, northern Italy.
(Courtesy of NASA)

FIGURE 15.5 St. Catherines Island, Georgia. Notice the distribution of sand, salt marsh (living), and salt marsh mud, plus the points where the three photographs were taken. A. View south–southeast from point **A** on map, at low tide. Dark-brown "ribbon" adjacent to ocean is salt marsh mud. Light-colored area is sand. B. View south from point **B** on map at low tide. C. View southeast from point **C** (Aaron's Hill) on map.

- **Delta**—a sediment deposit at the mouth of a river where it enters an ocean or lake. (emergent, FIGURE 15.2).
- **Headland with cliffs**—projection of land that extends into an ocean or lake and generally has cliffs along its water boundary (submergent, FIGURE 15.3).
- **Spit**—a sand bar extending from the end of a beach into the mouth of an adjacent bay (emergent, FIGURE 15.2).
- **Tidal flat**—muddy or sandy area that is covered with water at high tide and exposed at low tide. Tidal flats are best developed along emergent coastlines.
- **Saltmarsh**—a marsh that is flooded by ocean water at high tide. Saltmarshes are best developed along emergent coastlines (FIGURE 15.2).
- **Wave-cut cliff** (or *sea cliff*)—a seaward-facing cliff along a steep shoreline, produced by wave erosion. Wave-cut cliffs are best developed along submergent coastlines (FIGURE 15.3).
- **Wave-cut platform**—a bench or shelf at sea level (or lake level) along a steep shore, and formed by wave erosion. Wave-cut platforms are best developed along emergent coastlines (FIGURE 15.2).
- **Marine terrace**—an elevated wave-cut platform that is bounded on its seaward side by a cliff or steep slope (and formed when a wave-cut platform is elevated by uplift or regression; emergent coastline, FIGURE 15.2).
- **Stack**—an isolated rocky island near a headland cliff, best developed along submergent coastlines (FIGURE 15.3).
- **Tombolo**—a sand bar that connects an island with the mainland or another island. Tombolos are best developed along submergent coastlines (FIGURE 15.3).
- **Tied island**—an island connected to the mainland or another island by a tombolo (usually submergent, FIGURE 15.3).

ACTIVITY

15.3 Shoreline Modification at Ocean City, Maryland

THINK About It **How successful are efforts to protect shorelines from erosion by building artificial structures?**

OBJECTIVE Identify the common types of artificial structures used to modify shorelines and explain their effects on coastal environments.

PROCEDURES

1. **Before you begin**, read Human Modification of Shorelines below. Also, this is **what you will need**:
   - ___ ruler, calculator
   - ___ Activity 15.3 Worksheets (pp. 388–389) and pencil
2. **Then follow your instructor's directions** for completing the worksheets.

Human Modification of Shorelines

Humans build several common types of coastal structures in order to protect harbors, build up sandy beaches, or extend the shoreline. Study the following four kinds of structures and their effects in FIGURE 15.6.

- **Sea wall**—an embankment of boulders, reinforced concrete, or other material constructed against a shoreline to prevent erosion by waves and currents.
- **Breakwater**—an offshore wall constructed parallel to a shoreline to break waves. The longshore current is halted behind such walls, so the sand accumulates there and the beach widens. Where the breakwater is used to protect a harbor from currents and waves, sand often collects behind the breakwater and may have to be dredged.
- **Groin** (or *groyne*)—a short wall constructed perpendicular to shoreline in order to trap sand and make or build up a beach. Sand accumulates on the up-current side of the groin in relation to the longshore current.
- **Jetties**—long walls extending from shore at the mouths of harbors and used to protect the harbor entrance from filling with sand or being eroded by waves and currents. Jetties are usually constructed of boulders and in pairs (one on each side of a harbor or inlet).

ACTIVITY

15.4 The Threat of Rising Seas

THINK About It **How will rising sea levels affect communities along shorelines?**

OBJECTIVE Describe the probability of global sea-level rise and analyze the coastal hazards and increased risks it may cause.

PROCEDURES

1. **Before you begin**, read The Threat of Rising Seas below. Also, this is **what you will need**:
   - ___ calculator
   - ___ Activity 15.4 Worksheet (p. 390) and pencil
2. **Then follow your instructor's directions** for completing the worksheets.

The Threat of Rising Seas

The National Oceanic and Atmospheric Administration (NOAA), using measurements from satellite radar altimeters, estimates that global sea level has been rising at a rate of 2.9 mm/yr since 1992. Meanwhile, a 2013 report by Working Group 1 of the Intergovernmental

Panel on Climate Change (IPCC) of the United Nations Environment Programme (UNEP) has suggested that sea level will continue to rise and is now expected to achieve a mean global rise of at least 0.17–0.32 m (6.7–13.6 inches) by 2046–2065. Note that these figures are for mean (average) changes of global sea level. Specific locations may experience more or less of a rise in sea level. For example, although TOPEX/Poseidon satellite altimetry indicates that sea level is rising at a global rate of 2.9 mm/yr, NOAA tide gauge records indicate that sea level at Ocean City, Maryland (**FIGURE 15.7**), has been rising nearly twice as fast (5.48 mm/yr since 1975).

Sea level also fluctuates both above and below mean sea level during daily tidal cycles and storm surges. A **storm surge** is an abnormal rise of water pushed landward by high winds and/or low atmospheric pressure associated with storms. The storm surge is over and above the normal tide, and NOAA expresses it as the height above the expected tide level. NOAA also measures **storm tide**—which it defines as the water level height caused by a combination of the normal tide level and the storm surge. Storm surges can cause the ocean to rise by about 1–10 feet above the normal astronomical tide, depending on the magnitude of the storm and other factors. However, except for hurricanes, most storm surges are in the range of 2–3 feet.

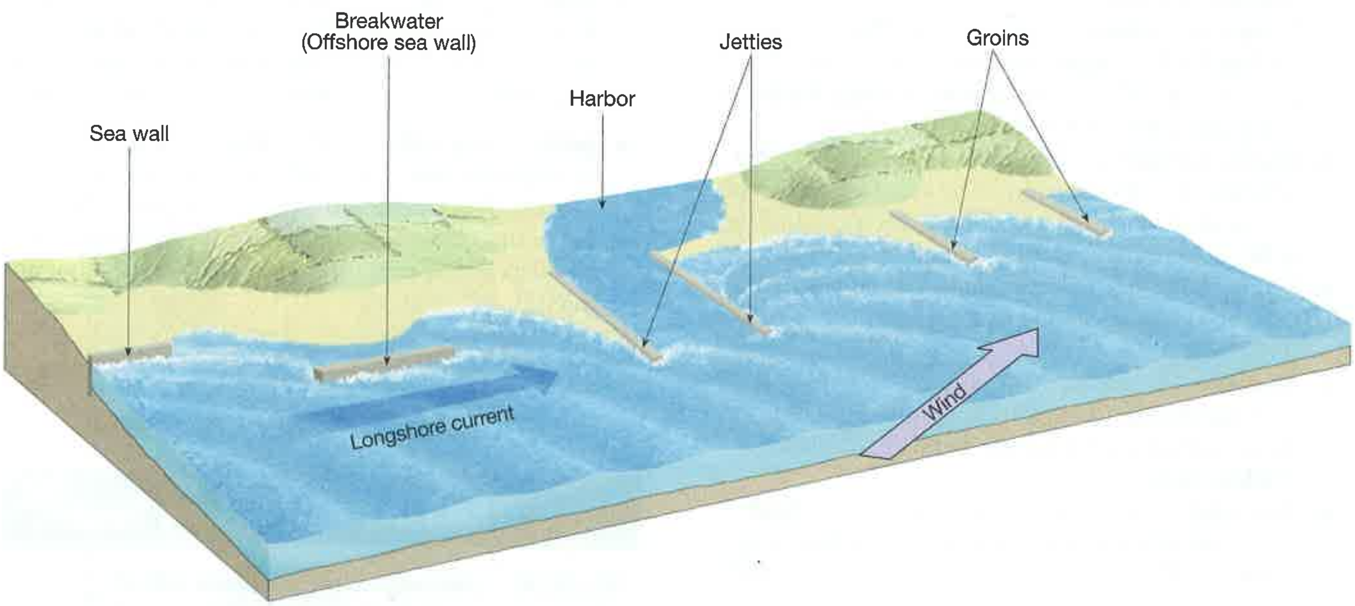


FIGURE 15.6 Coastal structures. **Sea walls** are constructed along the shore to stop erosion of the shore or extend the shoreline (as sediment is used to fill in behind them). **Breakwaters** are a type of offshore sea wall constructed parallel to shoreline. The breakwaters stop waves from reaching the beach, so the longshore drift is broken and sand accumulates behind them (instead of being carried down shore with the longshore current). **Groins** are short walls constructed perpendicular to shore. They trap sand on the side from which the longshore current is carrying sand against them. **Jetties** are long walls constructed at entrances to harbors to keep waves from entering the harbors. However, they also trap sand just like groins.

FIGURE 15.7: Ocean City, Maryland (1964) (Photorevised, 1972–purple areas)

(Courtesy of Courtesy of U.S. Geological Survey)

ACTIVITY 15.1 Coastline Inquiry

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. Refer to the photographs of coastlines in **FIGURE 15.1** and the list of Factors Affecting Coastlines on page 376.

1. Describe what each shoreline is made of (if visible). Then name the two or three main factors that are primarily affecting the coastline and describe how they combine to shape the coastline.

a. Maryland coastline with saltmarsh grasses rooted in clay.

b. San Francisco, California, coastline.

c. Oregon coastline.

d. North Carolina coastline.

e. Destin, Florida, urbanized coastline.

f. Florida Keys coastline with mangrove plants.

g. Maine coastline (note person for scale).

h. Caribbean island coastline with fringing reefs (i.e., reefs attached to the island) and a barrier reef.

B. **REFLECT & DISCUSS** **FIGURES 15.1C** and **15.1D** are both sandy coastlines. Which one is building out into the water and what is causing that to happen? Which one seems to be receding landward, and what seems to be causing that to happen?

ACTIVITY 15.2 Introduction to Shorelines

Name: ______________________ **Course/Section:** ______________________ **Date:** __________

A. Refer to the Space Shuttle photograph of the Po Delta, Italy (**FIGURE 15.4**). The city of Adria, on the Po River in Northern Italy, was a thriving seaport during Etruscan times (600 B.C.). Adria had such fame as to give its name to the Adriatic Sea, the gulf into which the Po River flows. Over the years, the Po River has deposited sediment at its mouth in the Po Delta. Because of the Po Delta's progradation, Adria is no longer located on the shoreline of the Adriatic Sea. The modern shoreline is far downstream from Adria.

1. What has been the average annual rate of Po Delta progradation in centimeters per year (cm/yr) since Adria was a thriving seaport on the coastline of the Adriatic Sea? (Show your work.)

2. Based on the average annual rate calculated above (A1), how many centimeters would the Po Delta prograde during the lifetime of someone who lived to be 60 years old? (Show your work.)

3. **REFLECT & DISCUSS** Sea level is rising and submerging coastlines adjacent to the Po Delta. Why do you think the delta prograding out into the Adriatic Sea?

B. Refer to the map and photographs of Saint Catherines Island, Georgia (**FIGURE 15.5**). Note that on the southwestern and east-central parts of the island there are large areas of salt marsh. Living salt marsh plants are present there, as shown on the right (west) in **FIGURES 15.5A** and **B**. Also, note the linear sandy beach in **FIGURES 15.5A** and **B**, bounded on its seaward side (left) by another strip of salt marsh mud. However, all of the living, surficial saltmarsh plants and animals have been stripped from this area. This is called **relict** salt marsh mud (mud remaining from an ancient salt marsh).

1. What type of sediment is probably present beneath the beach sands in **FIGURES 15.5A** and **B**?

2. Explain how you think the beach sands became located landward of the relict saltmarsh mud.

3. Portions of the living saltmarsh (wetland) in **FIGURE 15.5C** recently have been buried by bodies of white sand that was deposited from storm waves that crashed over the beach and sand dunes. What is the name given to such sand bodies?

4. Photograph 15.6C was taken from a landform called Aaron's Hill. It is the headland of this part of the island. What will eventually happen to Aaron's Hill? Why?

5. Based upon your answer in part 4, would Aaron's Hill be a good location for a resort hotel? Explain your answer.

6. **REFLECT & DISCUSS** Based upon your inferences, observations, and explanations above, what will eventually happen to the living salt marsh in **FIGURES 15.5B** and **C**?

ACTIVITY 15.3 Shoreline Modification at Ocean City, Maryland

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

Ocean City is located on a long, narrow barrier island called Fenwick Island. During a severe hurricane in 1933, the island was breached by tidal currents that formed Ocean City Inlet and split the barrier island in two. Ocean City is still located on what remains of Fenwick Island. The city is a popular vacation resort that has undergone much property development over the past 50 years. The island south of Ocean City Inlet is called Assateague Island. It has remained undeveloped, as a state and national seashore.

Rising sea level at Ocean City has increased the risk of beach erosion there. Therefore, Ocean City constructed barriers to trap sand. Examine the portion of the Ocean City, Maryland, topographic quadrangle map provided in **FIGURE 15.7**. Purple features show changes made in 1972 to a 1964 map, so you can see how the coastline changed from 1964–1972. Also note the black and red outlines of the barrier island as it appeared in 1849 and 2010 according to the U.S. Geological Survey.

A. After the 1933 hurricane carved out Ocean City Inlet, the Army Corps of Engineers constructed a pair of jetties on each side of Ocean City Inlet to keep it open. The southern jetty is labeled "seawall" on the map. Sand filled in behind the northern jetty, so it is now a seawall forming the straight southern edge of Ocean City on Fenwick Island (a straight black line on the map). Based on this information, would you say that the longshore current along this coastline is traveling north to south, or south to north? Explain your reasoning.

B. Notice that Assateague Island has migrated landward (west), relative to its 1849 position (**FIGURE 15.7**). This migration began in 1933.

1. Why did Assateague Island migrate landward?

2. Field inspection of the west side of Assateague Island reveals that muds of the lagoon (Sinepuxent Bay) are being covered up by the westward-advancing island. What was the rate of Assateague Island's westward migration from 1933–1972 in feet/year and meters/year? (Show your work.)

3. Based on your last answer above (B2), and extrapolating from 1972, in what approximate year should the west side of Assateague Island have merged with saltmarshes around Ocean City Harbor? (Show your work.)

4. Notice from the 2010 position of Assateague Island (red outline on **FIGURE 15.7**) that it has not merged with saltmarshes of the mainland. What natural processes and human activities may have prevented this?

C. Notice the groins (short black lines) that have been constructed on the east side of Fenwick Island (Ocean City) in the northeast corner of **FIGURE 15.7** (above 2 km north of the inlet).

1. Why do you think these groins have been constructed there?

2. What effect could these groins have on the beaches around Ocean City's Municipal Pier (southern end of Fenwick Island)? Why?

D. Hurricanes normally approach Ocean City from the south–southeast. In 1995, one of the largest hurricanes ever recorded (Hurricane Felix) approached Ocean City but miraculously turned back out into the Atlantic Ocean. How does the westward migration of Assateague Island increase the risk of hurricane damage to Ocean City?

E. Compare the position of Assateague Island in **FIGURE 15.7**, from 1972 (purple position of the island) to 2010 (red outline of the island). The northern two kilometers of the island remained in a relatively stable position from 1972–2010, but the rest of Assateague Island did not. Explain what happened to the southern three kilometers of Assateague Island on **FIGURE 15.7** from 1972–2010 and infer why it may have happened.

F. **REFLECT & DISCUSS** The westward migration of Assateague Island could be halted and probably reversed if all of the groins, jetties, and sea walls around Ocean City were removed. How would removal of all of these structures place properties in Ocean City at greater risk to environmental damage than they now face?

ACTIVITY 15.4 The Threat of Rising Seas

Name: ______________________ **Course/Section:** ______________________ **Date:** __________

In planning for coastal management and safe and economical coastal development, responsible planning commissions and real estate developers should "play it safe" and assume that sea level will continue to rise. There are many predictions of future rises in global mean sea level, but regional trends should also be considered as in these examples.

A. Imagine that you are planning to buy a shorefront property in Ocean City, Maryland, this year. You plan to use the property for family vacation getaways over the next 50 years and then sell the property. The front door of the property was four feet above mean sea level in 2010.

1. According to the U.S. National Oceanic and Atmospheric Administration, the historic rate of sea level rise here since 1975 has been 5.48 +/– 1.67 mm/yr. Using the "plus or minus" error, what has been the minimum rate and the maximum rate of mean sea level rise here in mm/yr?

a. ______________ mm/yr minimum rate **b.** ______________ mm/yr maximum rate

2. Using the minimum and maximum rates above, calculate how much sea level will rise in mm and inches at Ocean City over the next 50 years.

a. ______________ mm minimum **b.** ______________ inches minimum

c. ______________ mm maximum **d.** ______________ inches maximum

3. Mean sea level is the average position of sea level between low and high tides. High tides occasionally reach 2.9 feet (0.88 m) above mean sea level here, and storm surges often raise sea level an additional foot (0.3 m). When Hurricane Sandy passed offshore of Ocean City in 2012, the storm surge caused a total storm tide of 3.59 feet. Given these natural day-to-day variations in sea level, and the prospect of sea level rise calculated above, would it be a wise decision to purchase the shorefront property that you planned to buy? Explain your reasoning.

4. The City of Ocean City expects the following temporary increases in sea level due to storm surges in hurricanes. How would this affect your purchasing decision? Why?

Category 1 hurricane: 74–95 mph winds, Storm Surge: 4–5 feet

Category 2 hurricane: 96–110 mph winds, Storm Surge: 6–8 feet

Category 3 hurricane: 111–130 mph winds, Storm Surge: 9–12 feet

Category 4 hurricane: 131–155 mph winds, Storm Surge: 13–18 feet

Category 5 hurricane: 156 mph + winds, Storm Surge: more than 18 feet

5. REFLECT & DISCUSS Given the fact that most existing topographic maps of coastal areas have contour intervals of 5 feet, what would you suggest as the contour line below which construction of the living/working floor of homes should not occur along the Ocean City coast? Explain.