Beaches and Shorelines

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1 Introduction

In this handout, we will dive deep into everything related to the shoreline, such as key shoreline features, sand movements, and different bodies of waters. The study of the shore allows us to learn how the ocean interacts with the land, and sphere-to-sphere interactions like this is critical for earth scientists and students alike to understand.

2 Sand Movement

2.1 Light vs Heavy Wave Activity

A light wave is one with low energy. Thus, a beach near a light wave is characterized by a well-developed berm. (A berm is the gently-sloping/slightly elevated margin of the beach near the shore.) On the other hand, heavy wave activities are full of energy. The berm in this case will be under-developed and sandbars will be deposited offshore, just at where the wave breaks.

A summertime beach is characterized by light wave activities while a wintertime beach is characterized by heavy wave activities. How do you think the berm is affected in each case?

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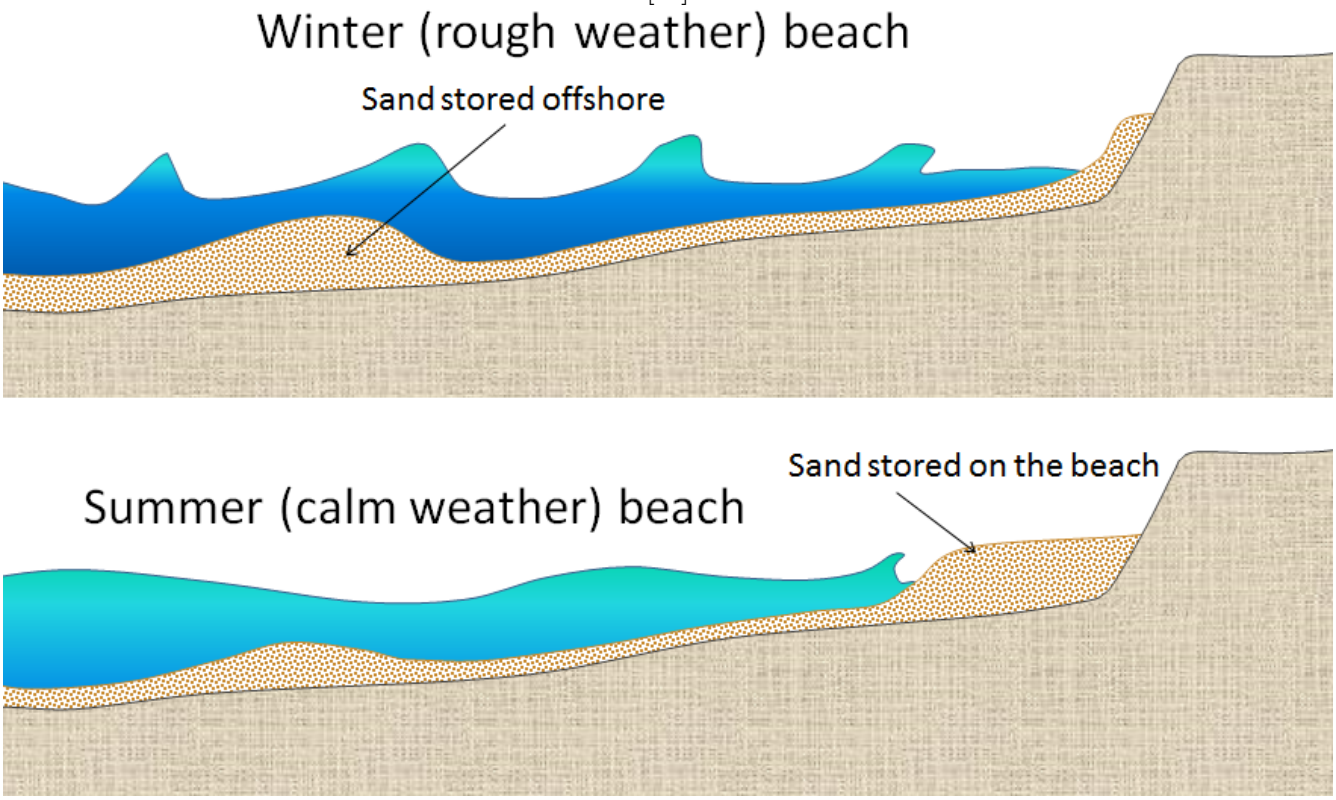

Figure 1: An image showing the difference between summer and wintertime beaches

2.2 Longshore Current

A **longshore current** is characterized by a zig-zag movement along a shoreline. How does this work?

As a wave approaches the shore at an angle (this is called the swash), the side closer to the shore "feels bottom" and refracts (bends) to be positioned more and more parallel to the shore. Once the wave hits the shore, gravity acts on it, effectively pulling it down (this is called the backwash). This contributes to the zig-zag wave pattern we see at a beach. Once the wave hits the shore, gravity acts on it, effectively pulling it down the beach face. This contributes to the zig-zag wave pattern we see at a beach.

Longshore transport indicates that, due to the longshore current, sands on a beach will be transported in a zig-zag pattern as well.

It's important to point out that longshore currents at both the east and west coast of the United States travel in a north-to-south direction. Why is the longshore current on the east coast traveling in the opposite direction of the Gulf Stream? Well, the direction of longshore currents are simply determined by the direction of the wave that propels these currents to form. Because storm centers tend to occur in the higher latitudes (50-60 degrees north), and their counterclockwise rotation causes surface waves to go south, propelling longshore currents that generally move north-south along either coast.

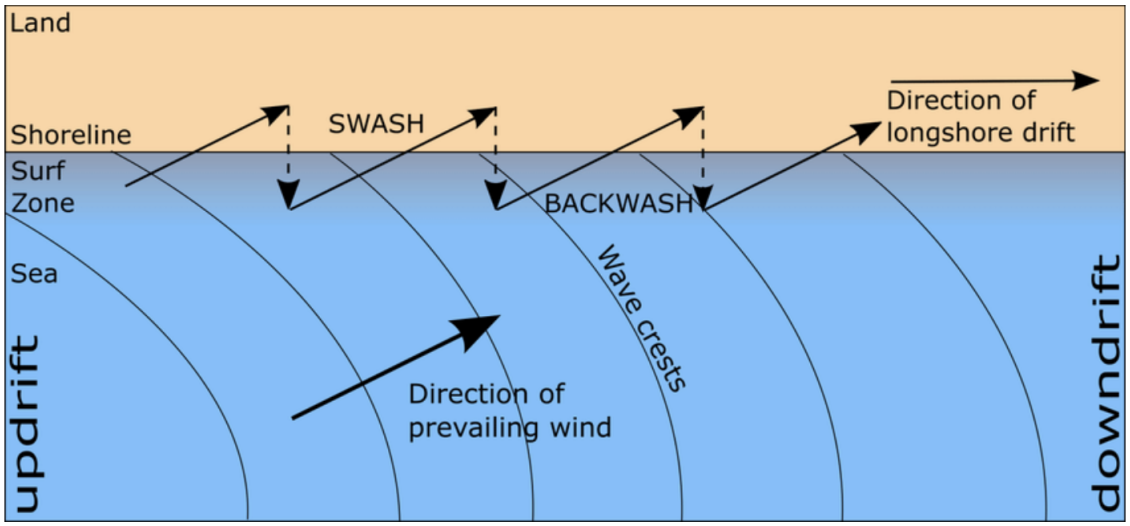

Figure 2: Longshore current transports sand in a zig-zag fashion. (Source: ResearchGate)

3 Erosional Shores

3.1 Features

An erosional shore is characterized by heavy erosion by waves. The **headland**, the feature of an erosional shore that stands closest towards the ocean, suffers the most erosion, alleviating wave

erosion on the features behind it.

When a **wave-cut bench**, which is the flat platform produced by wave erosion, undergoes uplift, the resultant, uplifted feature is a **marine terrace**. Overall, an erosional shore is said to be high-energy due to the high energy of the waves.

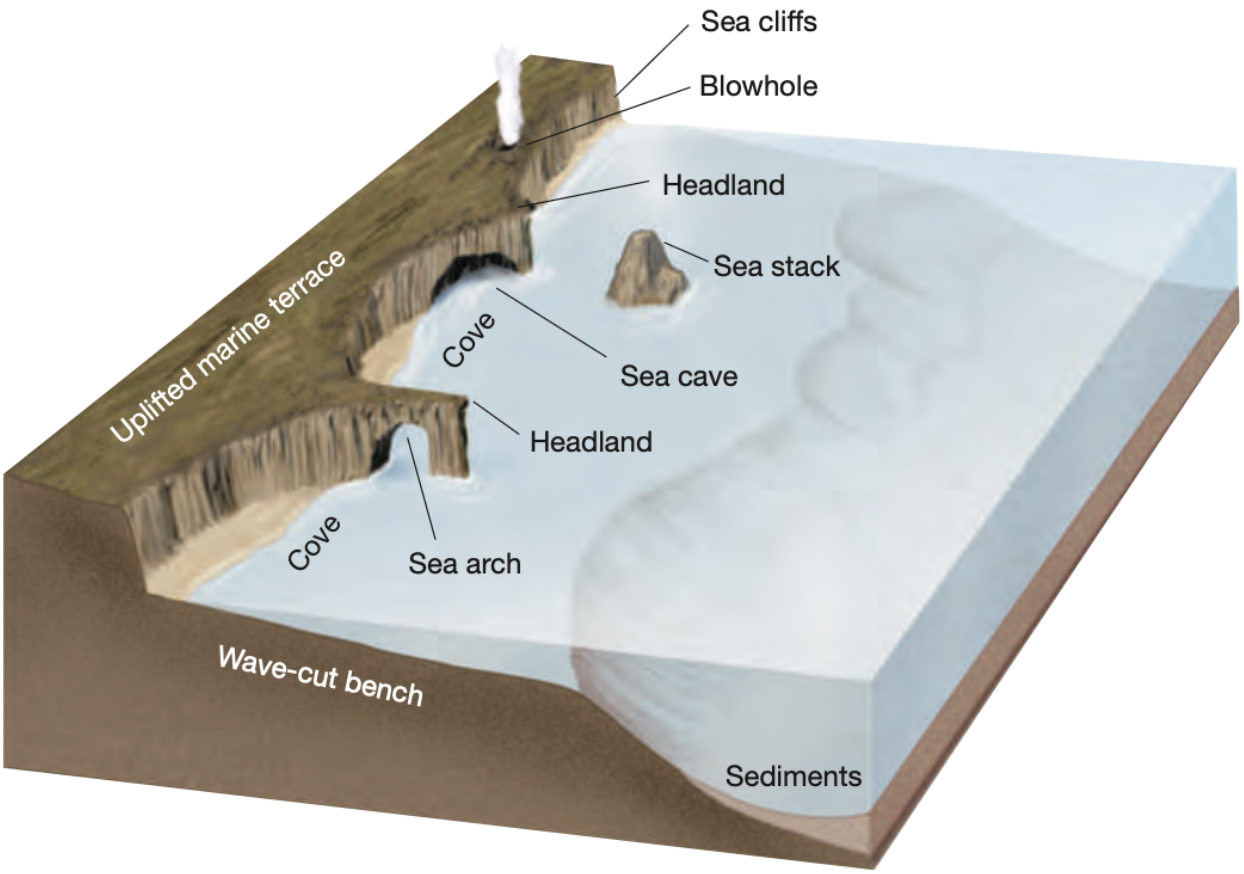

Figure 3: Features of erosional shores diagram. (Source: Trujillo)

4 Depositional Shores

4.1 Features

All these features are not super important to know but nevertheless good to know. We'll go over a few of the important ones, but you should know what each feature looks like.

- A **Spit** is a depositional feature which forms in the direction of current flow. Its edge can curve inside. When a spit grows long enough to connect to the mainland, it's called a **bay-barrier**.

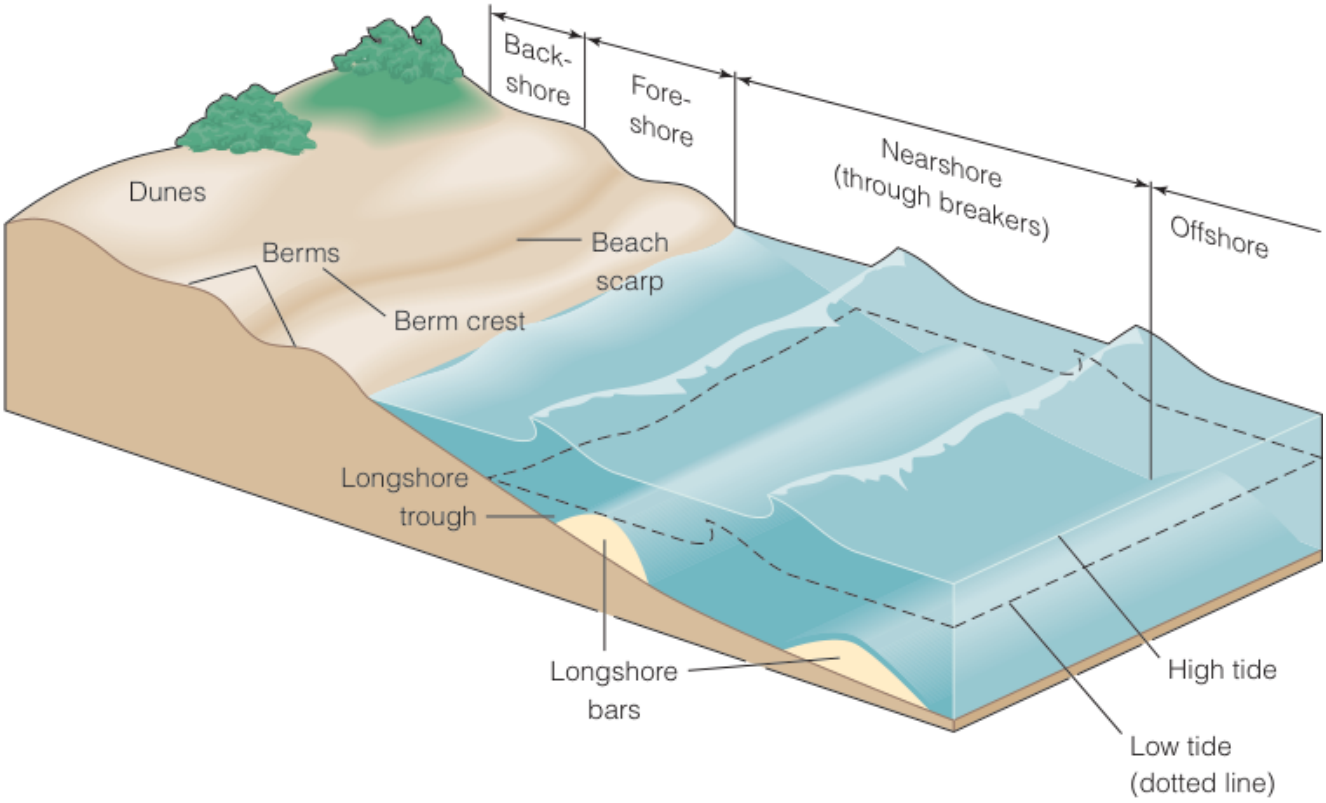

Figure 4: A view of the different zones of depositional shores

- A **Tombolo** is a sand ridge that connects an island to the mainland, usually perpendicular to direction of wave flow.

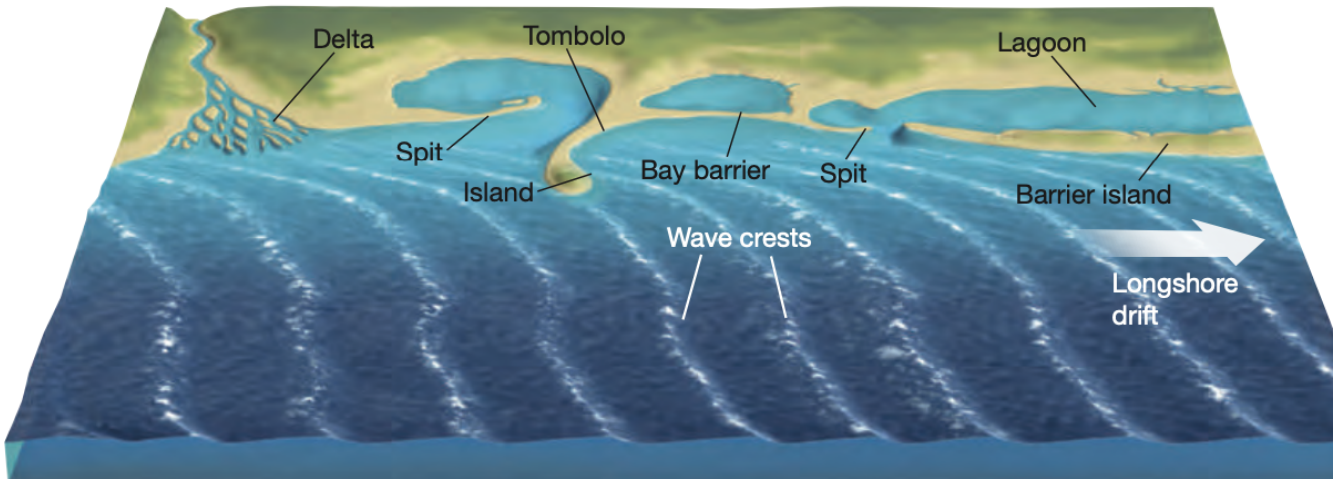

Figure 5: Features of depositional shores diagram. (Source: Trujillo)

5 Emerging and Submerging Shorelines

5.1 Features

- High cliffs: These are very steep to vertical bedrock cliffs that range from a few metres to hundreds of metres high. They are formed by wave erosion near sea level and the collapse of rocks above. They are common along erosional coasts with high relief and rugged topography.
- Headlands: These are protruding landforms that extend into the sea and are surrounded by water on three sides. They are formed by differential erosion of rocks with varying resistance along the coast. They often have sea cliffs on their sides and wave-cut platforms at their base.
- Exposed bedrock: This is the solid rock that is visible on the surface of the coast, usually as a result of erosion removing the overlying sediments. It can form waveplatforms, sea arches, sea stacks, and other rocky features along the coast.
- Steep slopes: These are inclined surfaces that connect the higher elevation of the coast to the lower elevation of the sea. They are formed by tectonic uplift, glacial activity, or mass wasting processes. They can be eroded by waves, wind, or rain.
- Rocky shores: These are coastal areas where rocks or boulders dominate the intertidal zone. They are formed by erosion of bedrock or deposition of coarse sediments along the coast. They provide habitats for various marine organisms that can withstand wave action and exposure to air.
- Arches: These are curved openings in the rock that span across the coast or an island. They are formed by erosion of softer rocks or joints in the bedrock by waves. They can collapse over time to form sea stacks.
- Stacks: These are isolated pillars of rock that stand near the coast or in the sea. They are formed by erosion of headlands or sea arches by waves. They can be eroded further to form stumps or submerged reefs.
- Tombolos: These are narrow strips of sand or shingle that connect an island to the mainland or another island. They are formed by deposition of sediments by waves and longshore currents along a submerged ridge or around a headland.
- Wave-cut platforms: These are flat surfaces of bedrock that extend from the base of a cliff to the low tide level. They are formed by erosion of bedrock by waves over long periods of time. They can be exposed during low tide and covered by sediments during high tide.
- Flooded river mouths: These are coastal areas where rivers meet the sea and form estuaries, deltas, or lagoons. They are formed by rising sea level submerging the lower parts of river valleys or by sediment accumulation blocking the river flow.
- Fjords: These are long, narrow, and deep inlets of the sea that cut into mountainous coasts. They are formed by glacial erosion carving Uvalleys that are later flooded by sea level rise.

- Barrier islands: These are long, narrow, and lowlying islands that run parallel to the coast and separate it from the open sea. They are formed by deposition of sand by waves and longshore currents along shallow offshore areas.
- Lagoons: These are shallow bodies of water that are separated from the sea by barrier islands, spits, or reefs. They are formed by sediment accumulation along the coast or by tectonic subsidence creating enclosed basins.
- Estuaries: These are coastal areas where freshwater from rivers mixes with saltwater from the sea. They are formed by flooding of river mouths by sea level rise or by sediment accumulation creating deltas.
- Bays: These are curved indentations of the coast that are partly enclosed by land and open to the sea. They are formed by differential erosion of rocks along the coast or by tectonic movements creating basins.
- Tidal flats: These are coastal areas that are exposed during low tide and submerged during high tide. They are formed by deposition of fine sediments such as mud and sand in sheltered areas such as estuaries, lagoons, or bays.

5.2 Causes

What causes a shoreline to emerge/submerge? There are two main reasons.

- **Tectonic Movements.** Often associated with tectonic uplift., volcanism can also be a factor. For instance, the US pacific coastline is emerging because there exists active volcanism, which continues producing mountain chains and uplift.
- **Isostatic Adjustment.** When a large continental glacier is present on a continent, its heavy weight pushes down the lithosphere. Once the glacier melts away, the lithosphere slowly bounces back. During the ice age, large glaciers were present in the northwest of present-day United States. Even though the glaciers all melted, the lithosphere is still slowly bouncing back, so the west coast is still rising in elevation.
- **Eustatic** refers to the distance from the center of the earth to the surface of the ocean. Eustatic sea level rise implies that the entire ocean level is rising, and not just at a single point (tides).

Example 2.1. (USESO Training Camp Hydrosphere Exam 2021) A geologist investigates a marine terrace, shown above. Which of the following could have been responsible for the formation of the marine terrace?

I) A decrease in eustatic sea level
II) Regional tectonic subsidence
III) Relatively high resistance to erosion of the exposed rock

A. I, only
B. II, only
C. I and II
D. I and III
E. II and III
F. I, II, and III

Solution: When sea level falls, the former wave-cut platform is exposed, forming the marine terrace. Marine terraces can also be formed by uplift, but subsidence is the opposite process and can cause the terrace to be submerged. The sea cliff is formed by wave action; the steepness of the cliff suggests bedrock which is resistant to erosion. Thus, we pick choice D.

6 Hard Stabilization

Hard stabilization is all about manually putting hard objects at beaches to prevent further erosion or encourage deposition in beaches that may be deficient in either. As you will see, this often leads to large consequences.

6.1 Various Methods

- **Groins.** Groins are built perpendicular to the shoreline to trap waves to deposit sands upstream. Deposition works well, but waves tend to cast drastic levels of erosion on the other side of the groin, downstream.
- **Jetties.** Jetties are essentially groins but much larger and longer. Their purpose is to protect harbor entrances from waves. The consequences of jetties are really the same as groins but much amplified, due to jetties being much larger.
- **Sea Walls.** A sea wall is used to protect a beach from wave damage. However, this hard stabilization method probably is the most consequential in the long run. Building a sea wall means that waves would be able to continuously pound against the beach without much deposition, eventually eroding the whole beach. The cost of repairing a sea wall then becomes much greater than the worth of the beach it protects.

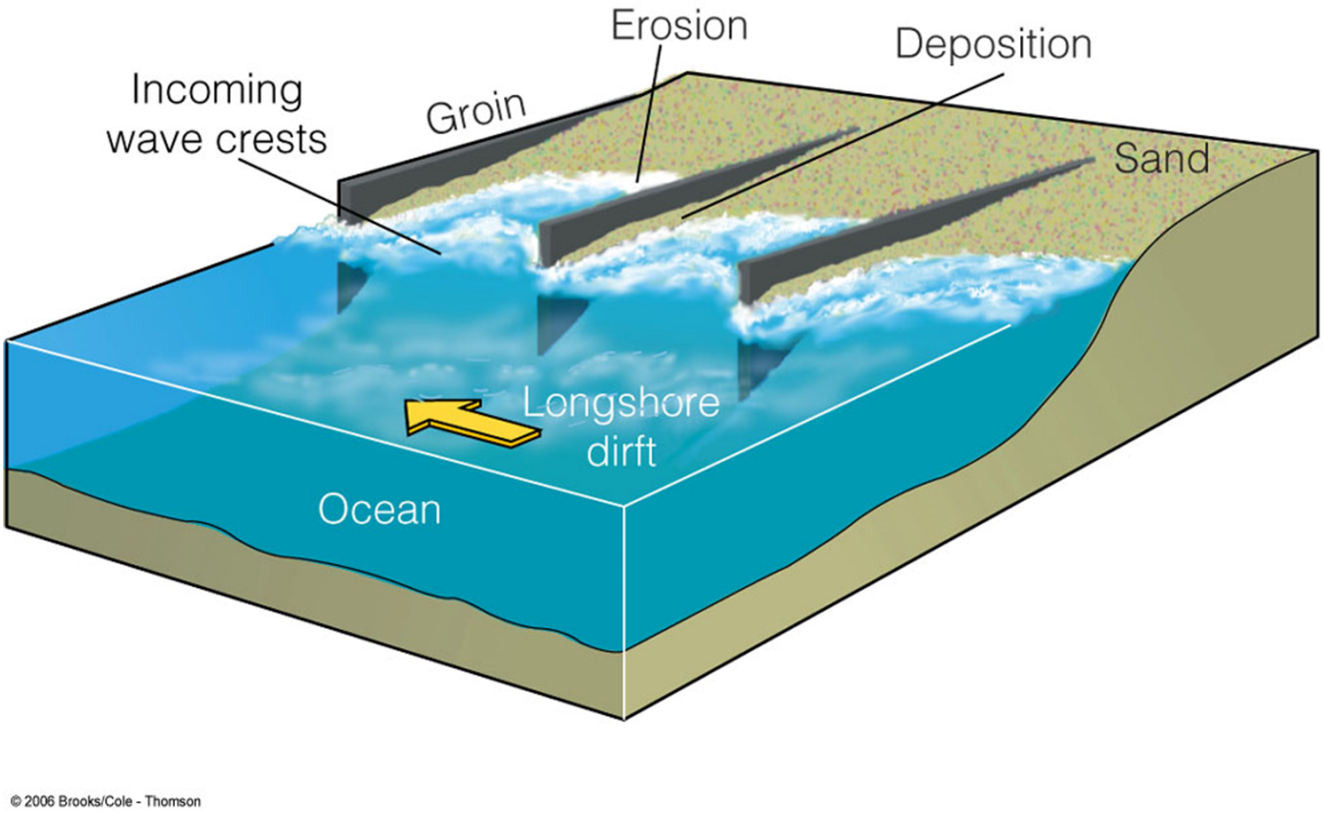

Figure 6: Groin field. (Source: Geophile)

7 Coastal Waters

This section focuses on different types of coastal waters and their special properties. Definitely the most important section to read!

7.1 Characteristics

- **Salinity.** In a coastal water body, runoff and offshore wind both have large effects on the water salinity. First, let's examine runoff. When runoff occurs from land, it's usually freshwater — and when this freshwater mixes with coastal salt water, the surface water becomes a lot less salty. When an offshore wind blows, some coastal water evaporates, leaving behind a greater concentration of salt; so in this case we see the surface water becoming a lot more salty.
- **Temperature.** In the low latitudes, the hot temperature makes the coastal water temperature relatively uniform as the entire water column is warmed. In the high latitudes, the cold temperature also makes the coastal surface water temperature similar to the deeper water, so the temperature is relatively uniform throughout. But in the middle latitude regions, sunlight makes the surface water relatively hotter, while the water at the bottom of the column is slightly colder. Winter wind can help make surface waters relatively colder.

7.2 Estuaries

An estuary is a partially-enclosed body of water where freshwater runs into oceanic salt water. There are four types of estuaries that oceanographers use (Figure 7).

- **Vertically mixed estuary** is a shallow estuary that is vertically mixed, meaning the salinity distribution is relatively uniform in the entire estuary.
- **Slightly stratified estuary** is a deeper estuary where at a certain depth, salty ocean water flows in the opposite direction as the surface freshwater. The freshwater and salt water are separated by a zone of mixing.
- **Highly stratified estuary** is one where the width of the salty ocean water underneath the estuary is even greater, and salty ocean water now often intrudes into the upper level freshwater.
- **Salt wedge estuary** contains a deep salt wedge which intrudes the estuary's freshwater above. The stratification of freshwater-to-saltwater is even greater in this type of estuary.

7.2.1 Case Study: Chesapeake Bay Estuary

The Chesapeake Bay Estuary is one of the most well-studied estuaries in America. Water enters the bay from the east side due to the Coriolis force, and thus circulates around the bay in a counterclockwise fashion (Figure 8). The bay has two layers of water: freshwater on top, and salty water beneath. The layers are separated by a strong halocline (the line that separates fresh and salt waters), as well as a strong pycnocline (the line that separates dense and less dense waters). Water is anoxic beneath the pycnocline in the summer, meaning it lacks oxygen. The anoxic water is due to human pollution such as nitrogen and phosphorous runoff.

8 Marginal Seas

Marginal seas are large bodies of water that remain somewhat independent from the world's oceans. Thus, their salinities and temperatures differ from the world oceans and are worth investigating.

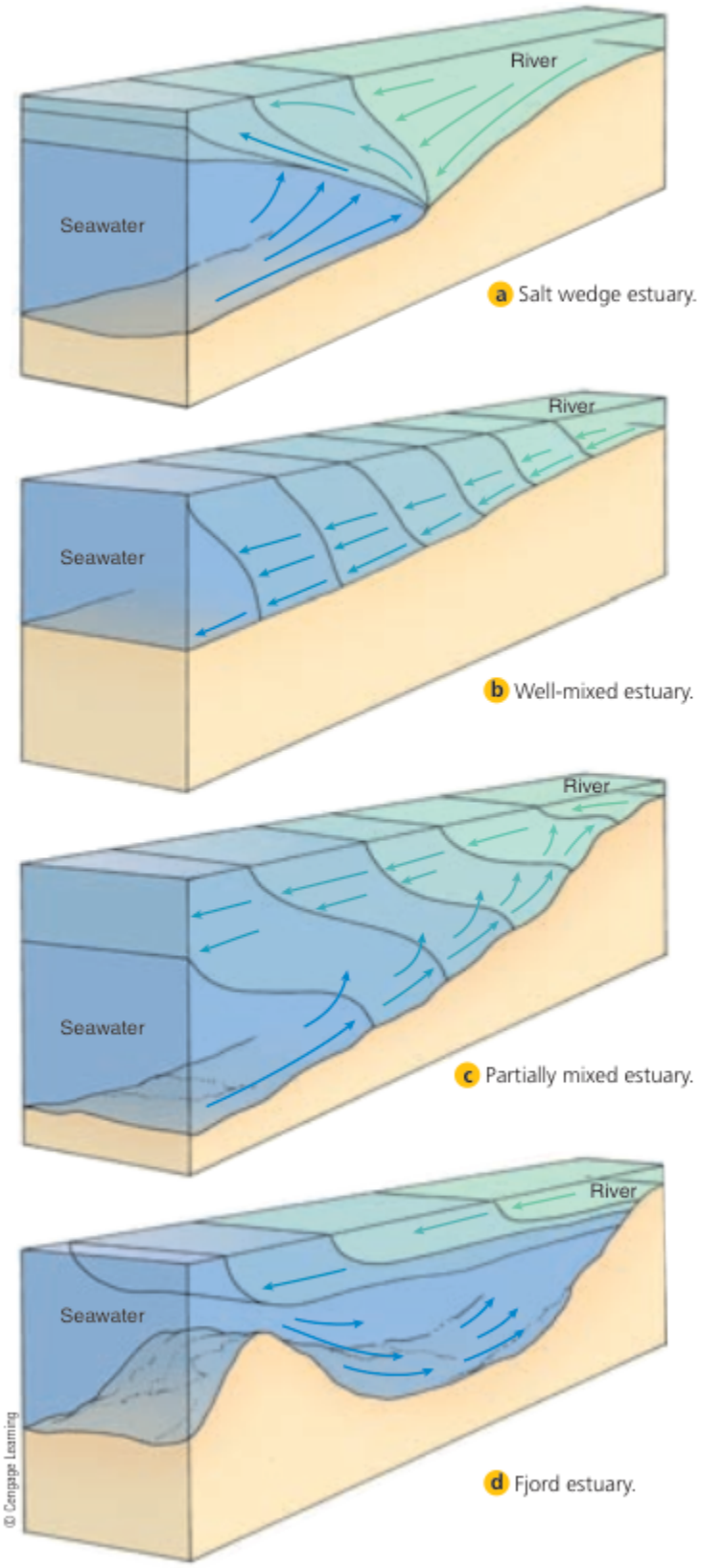

Figure 7: A diagram of the different types of estuaries and their stratification. Source: Garrison

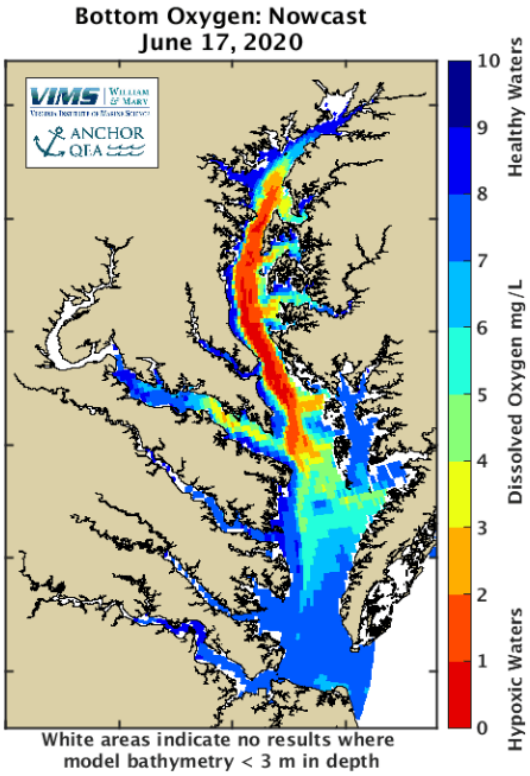

Figure 8: Diagram displaying distribution of hypoxic waters. (Source: VIMS)

8.1 Case Study: Mediterranean Sea

The Mediterranean Sea is a very interesting marginal sea to study, because its interaction with the Atlantic ocean drives its own Mediterranean Circulation. Its source of Atlantic water comes from the Strait of Gibraltar, which separates the Iberian Peninsula in Europe from Morocco in Africa. Now we will walk through the Mediterranean Circulation.

- The location of the Mediterranean Sea is exceptionally hot, and this causes plenty of evaporation on the east of the sea. This loss of water now allows the colder North Atlantic waters to enter the sea.
- In the winter, the Atlantic waters sink, forming the more saline Mediterranean Intermediate Water. This water flows west, ready to exit the Mediterranean Sea. The high density of this water is explained by the high evaporation rate in the Mediterranean.
- Finally, the Mediterranean Intermediate Water leaves the sea and spreads out at great depths of the North Atlantic Ocean, concluding the circulation.

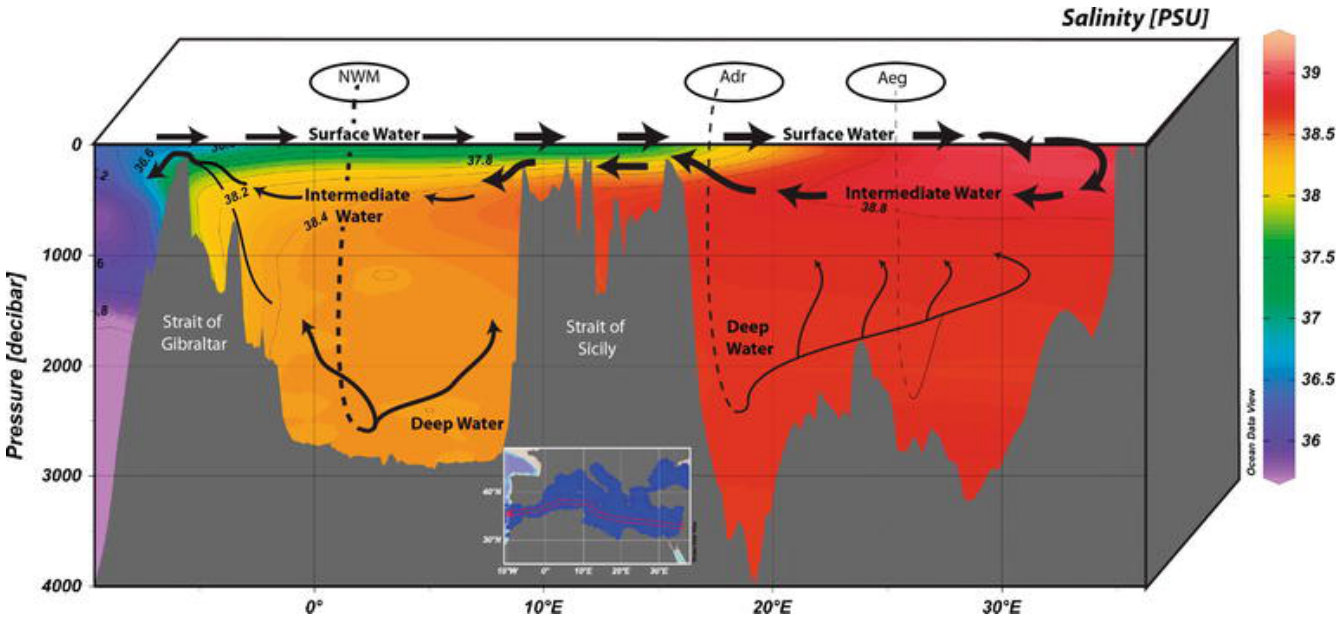

Figure 9: Cross-sectional diagram of the Mediterranean Sea Circulation. (Source: Pinterest)

9 Conclusion

Overall, beaches and shorelines are inevitably connected with the oceans, the continents, and also the atmosphere. Hopefully you were able to understand most of this handout; if some concepts confuse you, it is recommended that you learn more about sea-air interactions! Good luck.