CHAPTER 12 COASTS, BEACHES, AND ESTUARIES

Objectives

1. To acquaint you with the variety of coastal areas bounding the world's oceans, the different types and styles of coasts, and a generalized coastal classification based on processes.
2. To describe the anatomy and components of an active beach, the types of beaches, and an overview of the dynamic processes that occur on beaches daily and seasonally.
3. To examine a select group of beaches and coastal zones in detail.
4. To introduce you to the unique regions of the earth where freshwater environs and marine waters intimately interact to form some of the most beautiful and biologically productive areas on our planet.
5. To describe the dynamics of these estuarine systems in terms of water movements and balances, residence and flushing times, and to specifically look at temperate zone estuaries.

Key Concepts

Major Concept (I)

Coastlines are boundaries where land and sea intermingle and intimately interact, one of the most dynamic regions of our planet.

Related or supporting concepts:

- The coastal zone includes open coasts and bays and estuaries, i.e., a coastal zone is both land and water.
- The shore is the area from the outer limit of wave action on the bottom, seaward of the lowest tidal reaches, to the limit of the waves' direct influence on the land.
- The beach is an accumulation of sediment (commonly coarser grain sizes such as sands and gravels) that occupies a portion of the shoreline, commonly up to the high tide levels.
- Beach areas are not static, and sediments shift and move along, in, and out of beach or shoreline areas constantly.
- Coasts are classified as being either erosional or depositional depending on whether they predominantly lose or gain sediment.
- Most coasts along the eastern United States are passive coasts and are considered depositional.
- Most coasts along the western United States are active coasts and are considered erosional.

Major Concept (II)

All coastal areas fall into two major categories: Primary coasts and secondary coasts.

Related or supporting concepts:

- Primary coasts are created and maintained by terrestrial or land-based processes. Primary coasts may be formed by:
  a. erosion of the land and potential subsidence or sea level rises,
  b. sediments deposited at the shore by rivers, glaciers, or the wind,
  c. volcanic activity, and
  d. vertical movements of the shoreline by tectonic processes.
- Secondary coasts are created and maintained by predominantly marine processes. These coasts may be formed by:
  a. erosion by waves and currents,
  b. dissolution by seawater,
  c. deposition of sediments by waves, tides, and currents,
  d. erosion, deposition, and binding of sediments and skeletal materials by marine plants and animals.

- This genetic classification scheme is based on the origin of the dominant processes that shape coastlines, rather than the age or morphology of the coastline.

Major Concept (III)

To understand primary coastlines, we must recognize geological processes that bring materials to the edge of the land and into the sea

Related or supporting concepts:

- Glacial periods tie up seawater in land ice, lowering global sea level.
- Many features of current coastal areas are the direct result of glacial activities. These include erosional effects, such as the cutting of U-shaped river valleys, which may be subsequently flooded to create fjords (see figs. 12.1 and 12.4).
- Depositional effects, such as the formation of moraines may form barriers or islands and/or sills that may partially block entrances to fjords.
- Indirect glacial effects caused by sea level lowering include exposure of former shelf areas to river erosion and subsequent flooding (when the glaciers melt) to create drowned river or ria coasts (see fig. 12.5), and the isostatic rebound of coastal areas from removal of glacial cover, creating uplifted wave-cut terraces or beach plains.
- Many coastlines are completely dominated by sediments brought in by rivers from the interior. It is estimated that rivers carry 530 tons of sediment to the coastal environment each second. Erosion rates are estimated to be as high as 6 cm (2.4 in) from all land surfaces every 1000 yrs!
- Sediment carried to the coast by rivers helps to form and maintain beaches. Some of this sediment makes its way to the deep-sea floor.
- Coastlines characterized by high sediment supply and buffeted by strong prevailing winds are called dune coasts, due to the presence of sand dunes (see fig. 12.6).
- Volcanic activity can create flows that reach the sea creating lava coasts; in addition if the crater (i.e., source of the lavas) is located near or on the shoreline and is breached by the sea, it can be called a crater coast (see fig. 12.7).
- Tectonic activity along coastal faults can produce a variety of unique shorelines, such as fault bays, and fault coasts.

Major Concept (IV)

Secondary coasts are former primary coastlines that owe their present appearance to the ongoing activity of a variety of marine processes.

Related or supporting concepts:

- No matter how irregular a coastline's morphology is, marine processes constantly reshape it, smoothing its outline or appearance.
- Coastlines made of rocks with varying composition and resistance to erosive forces will temporarily have irregular outlines. More resistant rocks will form headlands or points that jut out into the sea. Progressive erosion of these headlands produces sea caves, arches, and sea stacks (figs. 12.2 and 12.10).
- Sea stacks are found in places including northern California, Oregon, Washington, Australia, and New Zealand.
- Eroded materials are often removed from the exposed beaches and deposited offshore. Three major types of deposits are commonly found:
    a. bars, which are linear sand deposits paralleling the shore in shallow water,
    b. barrier islands (fig. 12.11), which are essentially bars of sand where the sediment supply from the beach and longshore currents has been sufficient to break the surface. These are commonly stabilized by plant growth, but are extremely dynamic and constantly in motion (interference with and building on these islands has proven extremely costly) and,
    c. spits and hooks (fig. 12.13), which are bar-like deposits connected to the shoreline and often extended across the mouths of bays. If a spit continues to build offshore and happens to connect with an offshore island, it is called a tombolo .
- Barrier islands along the southeast coast of the United States formed during a period of rising sea level

when flooding inundated low-lying coastal areas and isolated the higher dunes at the former coastline.

- While barrier islands protect the continental coastline from storm erosion they do so by sustaining damage themselves. Severe storms and hurricanes have caused extensive damage and property loss on barrier islands.
- One of the great natural disasters in United States history was the 1900 Galveston hurricane. Galveston sits on Galveston Island, a barrier island along the Texas coast.
- Galveston was hit by a storm surge of 4.8 m (15.7 ft), destroying over 3,600 buildings in the city and killing an estimated 6,000 to 8,000 people (fig. 12.12).
- In tropical/subtropical coastal regions plants and animals may bind and trap sediment parallel to the shore, or create massive structures of their own skeletal materials. These systems are generally termed reef coasts.
- Low-lying tidal deposits, where sedimentation and plant growth have matched subsidence and recent sea level fluctuations, create great stretches of salt marshes (fig. 12.15). Salt marshes are extremely productive ecosystems, and many of the world's fisheries depend on their survival.

Major Concept (V)

The critical interface between coastal processes and terrestrial factors is the area of the shoreline we call the beach, including all of the deposits and processes from the lowest tide level up to the highest level that waves can inundate the coast.

Related or supporting concepts:

- Beaches can take on many different forms. The wide variety of features that can be associated with beaches are commonly displayed in a generalized cross section of a beach called a beach profile, such as the one shown in figure 12.16. Beaches may have some or all of these features.
- The shore may be subdivided into three major regions called the backshore, foreshore, and offshore.
- The offshore region is seaward of the beach. It includes shallow-water areas seaward of the low tide level out to the limit of wave action on the bottom. Seasonally mobile sand bars are often found in this region, trending parallel to the shore and separated by intervening troughs.
- The combination of the foreshore and backshore are what we call the beach.
- The part of the beach that remains exposed above the high tide water level is called the backshore. At any one season during the year the waves will create a berm on the backshore by cutting a scarp into the beach sediments that is terminated by a berm crest. The higher energy of winter waves will create a winter berm further up the backshore that will typically remain throughout the year while lower-energy summer waves create summer berms closer to the water's edge that will be erased by the next winter's storm waves.
- Two major features that we may see in the foreshore are low tide terraces cut by wave action during the low tide and a steeper slope extending up to the exposed part of the beach, called the beach face, which extends from the low to the high tide water levels including the swash zone.
- Some shorelines do not have visible beaches, instead they may simply have cliff faces.

Major Concept (VI)

Beaches are often described in terms of their shape and structure, the composition and grain size of the sedimentary particles, and occasionally by color.

Related or supporting concepts:

- The shape and structure of beaches are controlled by the interaction of waves, tides, currents, and the availability and nature of supplied sediments.
- Beach deposits may have a wide variety of compositions ranging from the skeletal remains of organisms to particles derived from sedimentary, metamorphic (e.g., shales), and igneous rocks (that include volcanic rocks and rocks such as granite).
- The composition and structure of the rock materials makes for some very interesting beach materials. Many of you may have experienced a high-energy beach where particles roll around in the high surf action, forming rounded cobble beaches; yet where laminated flat sediments or metamorphic rocks, such as shales, slide around on the beach, a shingle beach may be formed. Shingles are flat, circular, smooth stones.

- When particles roll rather than slide, they are rounded. These particles are classified by size using terms such as sand, mud, pebble, cobble, and boulder.
- High-energy erosional beaches can form lag deposits when the finer sand-sized material is eroded away. The extreme case would be where very large rocks are left on the beach creating an armored beach.
- Unusual beach colors should clue you in immediately that there may be an exotic source for the beach material, such as the white sand beaches and black sand beaches of Hawaii, formed by coral fragments and eroded and transported basaltic lavas, respectively. Broken shell fragments can create pink beaches.
- The composition and size of beach material are related to the source of the material and the physical processes acting on the beach.

Major Concept (VII)

Beaches are created, maintained and destroyed by extremely dynamic processes. Even beaches that appear year after year with little or no apparent changes are in a state of dynamic equilibrium with the processes that build them and those that would destroy them.

Related or supporting concepts:

- Gentle summer waves tend to deposit sand onto the beach, while stronger winter storm waves (that may come from quite a different direction) will remove sandy materials from a beach, depositing them offshore as sandbars (see fig. 12.19).
- Waves approaching the coast within the surf zone produce a current, whereby particles of suspended and bottom sediments are transported onshore in what are termed onshore current and onshore transport, respectively.
- As wave crests do not approach or break in the surf zone exactly parallel to the coast, the small angular difference sets up another current, called the longshore current.
- Longshore currents actively transport beach sediments, especially during storm wave conditions. As the waves strike and swoosh up into shallow water at a slight angle, the water flowing off the beach also moves off the beach face with a slight angle, moving both fluids and particles down current (fig. 12.20).
- Sediments are being transported southward along much of the eastern and western coastlines of the United States.
- In many cases we can discuss a discrete portion of a coastal area that contains both the source area for the beach sands along its length, and the primary area of net deposition of these sands. Such generalized zones are termed drift sectors (fig. 12.22).
- Beaches within these drift sectors usually remain in dynamic equilibrium and will appear to change little over long periods of time. However, at the source end beaches may be eroding, whereas at the other end of the cell, beaches are primarily depositional.

Major Concept (VIII)

As waves move into shallow water and break, water is moved shoreward into the coastal zone and actually piles up in the near shore surf zone. The return of this water is necessary and forms an important part of local coastal circulation.

Related or supporting concepts:

- Water accumulating onshore moves offshore in areas called rip currents (fig. 12.23). These are fast moving, narrow, seaward flowing currents.
- Some of the sediment carried offshore by a rip current will be deposited in the deeper water while the rest of the sediment will be driven back toward the beach by the onshore transport on either side of the rip current.
- This pattern of partial return of sediment to the beach, transport along the beach, and back offshore by the next rip current is called a drift sector (fig. 12.22).
- A series of drift sectors can be linked together to form a coastal circulation cell (see fig. 12.24). At the end of a coastal circulation cell the sediment is transported far enough offshore that it is not recycled

back to the beach.

- On the west coast, many circulation cells end with longshore drift and larger scale rip currents depositing sediments at the heads of submarine canyons. These sediments are effectively removed from continuing down the coast, and are routed into much deeper water in turbidity flows.
- Estimates of longshore transport of sediments on beaches range from zero to millions of cubic meters per year. Averages range from 150,000 m^3/yr to 1,500,000 m^3/yr. If 150,000 m^3/yr = 30,000 dump truck loads, the high average load is about 822 dump trucks of sand per day moving into, onto, and out of a coastal beach zone (one truck about every two minutes!).
- The energy (about 10^{14} watts) for this momentous transport system is provided by wind-driven waves and wave-generated currents (longshore drift).
- There are about 440,000 km, or 264,000 miles, of coastal areas on earth. Roughly half of these regions are directly exposed to these dynamic forces.

Major Concept (IX) *Any artificial or man-made substance or structure placed in the beach zone will interfere with the coastal circulation of water, sediments and the energy distributed in the beach zone. Coastal alterations, and any changes in the supply of sediment to our beaches, must therefore, be very carefully considered.*

Related or supporting concepts:

- Coastal regions are generally densely populated and very susceptible to environmental damage.
- Roughly 60% of the world population lives within 100 km (60 mi) of a coastline. In the United States over one-half of the population lives within 80 km (50 mi) of the coasts (including the Great Lakes).
- Many rivers are now dammed for their inland water and power resources, trapping and preventing sediments from reaching the coasts and contributing to the littoral pattern. This removes sediment sources for down current beaches.
- Breakwaters, jetties, groins, etc., all interfere with the longshore drift of water and sediments down the coastal cell. Groins, for example, trap sediments on their up-current sides and accelerate erosion on the down-current side.
- Poorly planned use of beach protection structures cause down-current residents and communities to put additional structures in to save themselves from up-current protection; creating an effect that ripples on down the coast.
- More than forty percent of U.S. shorelines are losing more sediment than they receive, and in many places, costly beach nourishment or replenishment programs have been initiated to combat this nation-wide loss of coastal real estate (see fig. 12.29). The U.S. Army Corps of Engineers has targeted about 4300 km (2700 mi.) of coastline as critical areas needing public protection. Unfortunately, the legacy of our past mistakes with coastal structures indicates we have tried more to control than understand coastal dynamics.
- Most of the areas designated critical are along the Atlantic and Gulf coasts. Many of these areas are barrier islands.

Major Concept (X) *Detailed working models, mathematical or computer simulations, and other techniques must be used before coastal structures are designed and built.*

Related or supporting concepts:

- Santa Barbara harbor is a classic example of interference in longshore sediment dynamics with completely predictable consequences (fig. 12.30). The jetty interferes with wave energy and the longshore current, thus creating a wave shadow, and continuously depositing sediments to the north of, and within, the very harbor the breakwater was designed to protect. Moreover, beaches to the north were gaining sediments, while beaches southward were experiencing extreme erosion. To complete the longshore cycle with less detrimental effects, a dredge now continuously pumps sediments from the inner harbor to the beaches on the south, replenishing them, and retaining sand in the local cell.
- Ediz Hook, seen in figure 12.31, protects the harbor of Port Angeles, Washington, and is a spit of sand and gravel in a state of severe erosion since the spit is sediment starved (its supply is gone).

- Ediz Hook was probably stable for the last 14,000 years or so until 1911 when two dams were constructed across the Elwha River to provide power and a freshwater reservoir. These dams prevent sediments that used to replenish the spit from reaching the coastal cell. The Army Corps of Engineers will spend over $30 million in the next 50 years to protect the spit, which in turn protects a harbor area with projected revenue over the same time frame of about $425 million.
- The dams also block the annual salmon run on the river.
- Federal law was enacted in 1992 that authorized the removal of the dams to restore the salmon run. Once the dams are removed, the natural transport of sediment to the hook will be restored also.

Major Concept (XI) *An estuary is a coastal embayment isolated from open ocean conditions, whose waters are diluted by freshwater input from rivers. Estuaries are classified by their circulation dynamics and patterns, and by the vertical distribution of salinity.*

Related or supporting concepts:

- Estuaries are places where tidal, oceanic, and river processes interact.
- The simplest type of interaction of a river flowing directly into the sea occurs in a salt wedge estuary (see fig. 12.32). In these systems, circulation and mixing are controlled by the rate of river discharge. The discharge of fresh water is in a thin layer above a salt wedge that can move upstream on the rising tide or at low flow rates. Examples include rivers such as the Columbia, Mississippi, and the Sacramento.
- Estuaries that are not of the salt wedge type are commonly divided into <u>three</u> additional categories on the basis of their circulation and vertical distribution of salinity. These are:
    a. the well-mixed estuaries—with strong tidal mixing and low river flow (i.e., salinity decreases with distance away from the sea yet is uniform vertically, see fig. 12.33).
    b. the partially-mixed estuaries—these systems have a strong surface river flow and a matching strong inflow of seawater at the bottom (see fig. 12.34). At the interface, seawater and fresh water are mixed by tidal turbulence and entrainment to produce a large seaward surface flow.
    c. the fjord-type estuary—these systems are the least mixed due to weak tidal flows and severe stratification (see fig. 12.35). Fresh water exists relatively unmixed at the surface while seawater enters slowly at depth. The bottom water in fjords may become stagnant and anoxic due to isolation caused by sills at the mouth of the estuary and the slow rate of replacement.
- If we wish to break down estuary types even further, we would look carefully at the degree of stratification with depth using salinity as our guideline.
- Processes that control the degree of vertical stratification are:
    a. the strength of oscillatory tidal currents,
    b. the rate of fresh water addition,
    c. the roughness of the flow boundary conditions or bottom topography, and
    d. the average depth of the estuary.
- Not all estuaries fit into this simple classification scheme and any given estuary may alternate between estuary types seasonally or throughout the lifetime of the estuary.

Major Concept (XII) *To understand general circulation patterns in bays and estuaries we will examine a system midway between extremely well mixed and totally stratified: the partially-mixed estuary.*

Related or supporting concepts:

- Partially mixed estuaries are the best examples to study because they have measurable inflow at depth from the sea and a large outflow at the surface of mixed fresh and seawater.
- A critical concept is that tidal currents move water back and forth in the estuary on the falling and rising tides, however, many tidal cycles may be required to observe net movements into or out of the estuary.
- This concept of net circulation is critical for understanding natural and man-made interactions with estuarine systems as:

a. waste and other material deposited in estuaries take time to actually leave the system,
b. circulation patterns control the outflow of nutrients and organics from the land towards the sea,
c. many species of marine organisms spend their juvenile stages living in estuaries, and
d. essential nutrients are brought into estuaries with seawater inflow at depth.

- Direct measurement techniques to track parcels of water into and out of the estuary are very costly and not practical in most cases.
- A less expensive and simpler (but less accurate) method of calculating circulation inflow and outflow is through creation of a water budget. If we assume that the estuary has a constant average volume of water, we can say that all activities that add water to it must be balanced by outflows (like our example of an unchanging beach in dynamic equilibrium, see figs. 12.36 and 12.37).
- In order to obtain the water budget we need to know the relative amounts of fresh and salt water in the outflow. This can be determined by calculating a salt budget that requires knowledge of two components, the salinity of the outflowing surface water (S_o) and the average salinity of the incoming seawater or oceanic input (S_o). The fraction of river water in the outflow is equal to:

$$(S_i - S_o) / S_i$$

- We can therefore set up a simple equation to approximate the inflow and outflow. For example, if we remember that in a partially-mixed estuary we expect the total seaward flow of mixed river and seawater (T_o) to be the result of contributions from both river input (R) and salt water inflow (T_i) where:

$$T_o = T_i + R$$

- If we know the river fraction going out mixed with seawater and the total freshwater river input, we can estimate all of the other components without direct measurements by:

$$R = T_o \; ((S_i - S_o) / S_i)$$

and by rearranging this equation:

$$T_o = R \; (S_i / (S_i - S_o))$$

- These are very simple approximations and can be affected by local evaporation and precipitation within the estuary and actual changes in volume or salt content over time.
- We can easily see why knowing the oceanic component in any of these calculations is extremely important by considering a typical temperate zone estuary where evaporation is roughly equal to precipitation and S_i = 33 ppt and S_o = 30 ppt (most of the world's estuaries fall into this category). In these estuaries, the total seaward flow is typically 11 times the river input, therefore seawater influx at depth is about 10 times the flow of fresh water at the head of the estuary.

Major Concept (XIII)

Embayments near 30˚ N and S have low precipitation and high evaporation rates. Although they are not true estuaries, the dominance of evaporative processes creates a unique reversal of inflow and outflow in inverse estuaries.

Related or supporting concepts:

- For inverse estuaries, the total seaward flow of mixed river and seawater T_o occurs at depth because it has a high salinity and is very dense. The salt water inflow T_i occurs at the surface. River input is minimal (see fig. 12.38).
- If evaporation is equal to or greater than river input, the inverse estuary is likely to have an even smaller ratio of river input to outflow than temperate zone estuaries (less than 1 to 11) and therefore, a much more rapid exchange with the ocean basin.

Major Concept (XIV) *The time required for an estuary to completely exchange its water is similar to our concept of residence time and is termed flushing time.*

Related or supporting concepts:

- Flushing time can be calculated by dividing the average volume of the estuary by the seaward rate of outflow.
- Rapidly flushing systems can quickly cleanse themselves of pollutants and debris while slower flushing systems cannot handle them as easily.
- Bays or harbors that are not truly estuaries (lacking isolation from the ocean or freshwater dilution) still have measurable flushing times because of tidal circulation. An intertidal volume moving in and out of the system can be calculated for these regions. Flushing times can be calculated by dividing the volume of the bay by the intertidal volume exchanged per tidal cycle.
- Multi-layer stratification, incomplete mixing, and slow tidal currents may complicate these simple calculations. Moreover, seasonal changes in oceanic conditions may increase or decrease inflow to these systems.

Major Concept (XV) *Although each estuary is unique, we can learn a great deal from two case histories of specific estuaries.*

Related or supporting concepts:

- San Francisco Bay: A critical West Coast estuary of 1240 km^2 (480 mi^2), whose river systems drain fully 40% of the surface area of the state of California! However, the bay has been subject to tremendous alterations since the first Spanish settlements in 1769.
    a. The bay's real developmental impact occurred after the 1848 gold rush, which resulted in an increase in the population of San Francisco from about 400 to 25,000 in 1850.
    b. Sediments from mining activities rapidly entered the bay.
    c. Marshes began to disappear and freshwater was removed for irrigation.
    d. A variety of non-native animals were introduced to the bay, displacing native animals.
    e. The bay's fisheries (salmon, sturgeon, sardines, flatfish, crabs, and shrimp) were heavily exploited in the mid to late 1800s, and by 1900 most had been overharvested and collapsed.
    f. Dikes were built around marshlands for agriculture, homes, and industries, reducing wetlands from 2200 km^2 (860 mi^2) to 125 km^2 (49 mi^2).
    g. River inputs have been decreasing yearly as the water is diverted for agricultural use (irrigation) and public drinking water sources. By the year 2000, San Francisco will receive only 30% of its 1850 freshwater supply.
    h. Contaminants of all kinds, including fertilizers, pesticides, salt leachates, and domestic and industrial wastes have destroyed or threatened much of the surrounding wetlands, reservoirs, and the bay itself. San Jose is attempting to reverse this trend by reducing effluent discharges and creating new habitats for wildlife.
    i. Intensive studies are now underway to monitor the bay and its wetlands in order to begin to make intelligent management decisions.
- Chesapeake Bay: A shallow, drowned river valley with a water surface area of 11,500 km^2 (7000 mi^2) and an average depth of 6.5 m (21 ft). As you would imagine, such a large estuary has a long flushing time of 1.16 years, making the bay and the surrounding wetlands extremely sensitive to alterations and contamination.
    a. Chesapeake Bay is a tremendously productive area long besieged by population pressures (since colonial times).
    b. Domestic and industrial wastes have wreaked a terrible toll on the overall health of the bay, all but destroying the oyster, crab, and rockfish fisheries. These wastes have caused lowered oxygen values in the water and the substrate as well as outbreaks of infectious diseases (typhoid fever) and red tides.
    c. The bottom sediments of Chesapeake, like other estuaries near industrial centers, now contain

a legacy of trapped toxic contaminants.

d. Efforts to improve and clean up the bay have generated nearly 4000 studies since the 1970s. Still, some 4 trillion gallons of waste water enter the bay each year (20% of the bay's total volume).

e. A $27 million "SAVE THE BAY" campaign began in 1983, however, the basic problem is how we can completely stop dumping into the bay (for example, Virginia and Maryland industries still dump approximately 3100 tons of heavy metal into the bay each year).

f. Finally, with such a large estuary, relatively long flushing time, and extensive wetlands, seasonal climate effects such as surges in freshwater input and peaks in salinity can be very dramatic in the bay.

Matching Key Terms with Major Concepts

At the end of the chapter in the textbook is a list of key terms. You should be able to match each of these with one of the previously listed major concepts. To test your ability, try to match the following key terms with the number (I–XV) of the appropriate major concept identified in this section:

breakwater	jetties	groins
longshore current	delta	sand spit
fjord	moraine	sill
hook	offshore	littoral drift
bar	backshore	berm
littoral cell	beach	barrier island
foreshore	dynamic equilibrium	salt wedge estuary
fjord-type estuaries	water budget	oceanic input
inverse estuary	intertidal volume	estuary
well-mixed estuary	net circulation	river input
total seaward flow	partially-mixed estuary	flushing time
sea stack		

Test Your Recall

Answer the following questions to test your understanding

FILL IN THE BLANK

1. ____________________ are areas of the world where land meets sea.
2. The ________________ is an accumulation of sands and gravels that occupy a portion of the shore.
3. Coastlines formed through tectonic activity (uplift and crustal movements) are classified as ______________________ coasts.
4. Coastlines formed by dominantly marine processes are termed ______________________________ coasts.
5. A _______________ is essentially a drowned glacial valley.
6. A mound of glacial sediments deposited at the edge of a glacier is called a _________________________.
7. A ________________ is a deposit of river borne sediment accumulating at the river's mouth.
8. Coastal cliffs of widely differing types of rocks resisting erosion in varying degrees often have isolated rocky islands or pinnacles offshore termed __________ ___________________.
9. _____________ and ______________________ _______________________ are offshore deposits of sands paralleling the coastline.
10. A beach that does not appear to gain or lose sediments over time is said to be in a state of

______________________ ______________________________.

11. ____________________ waves tend to deposit sand on beaches, while ____________________ waves remove it to offshore bars.
12. A ___________________________ _____________________ is a surf zone current, generated by waves, that moves down the beach.
13. The transport of sediments along the shoreline near the beach is called ________________________ _______________.
14. Water, returning to the offshore after accumulating in the surf zone, returns in fast-moving _________ ________________________.
15. There are ______________________ kilometers of coastline or coastal zones in the world.
16. An _____________________ is an embayment of the ocean somewhat isolated by land whose waters are diluted by freshwater drainage.
17. ____________ _______________ estuaries occur near the mouth of a river flowing directly into the sea.
18. The one-sided mixing of entering seawater into the outflowing fresh surface water, in a salt wedge estuary, is termed _________________________________.
19. Well-mixed estuaries have __________________ _______________ mixing and _________ _______________ flow.
20. In well-mixed estuaries, ________________________ and _________________________________ are uniform over depth.
21. ___________________________ - _______________ estuaries have a strong net seaward surface flow of fresh water and a strong inflow of seawater at depth.
22. The transport of salt into an estuary by flowing water is termed ___________________________.
23. Fjord-type estuaries are ____________, and have high river input with little _______________ mixing.
24. To further divide estuary sub-types, we look carefully at the degree and style of vertical ____.
25. The _________ _________________________________ of an estuary is critical, as it determines how debris and wastes move around in the estuary and how they are dispersed in the sea.
26. A water budget involves all water __________________ and _____________________ into the estuary.
27. A ____________ __________________ tracks the salinity input of seawater versus the salinity of outflowing mixed fresh and oceanic waters.
28. In temperate zone estuaries, _________________________________ is very nearly balanced by _______________________________________.
29. Embayments near 30 degrees S and N have low _______________________________________ and high _________________________________ rates.
30. _____________________ ___________________________ have dense, salty water flowing out at depth, with less saline oceanic water flowing in at the surface.
31. The _________ _________ and the Mediterranean are two classic examples of inverse estuaries.
32. The time required for an estuary to completely exchange its waters with the oceanic system is called its ________________________ ____________.

33. The volume of water in a coastal embayment obtained by multiplying the area of the bay by the change in tidal water levels is called the ______________________________ __________________.

TRUE - FALSE

1. In most instances, coasts and beaches are static environments, and do not change much over long periods of time.
2. Primary coasts owe their origins to dominantly marine processes.
3. Secondary coasts owe their origin to dominantly tectonic processes.
4. A sill is a shallow lip, possibly of glacial debris, that is found near the mouths of some drowned river valleys.
5. A ria coast is the term used to describe a coastal system with prominent drowned river valley features.
6. The eastern seacoast of the United States, south of Cape Hatteras, has been formed by the coalescence of sediments from many river systems.
7. A coastline formed by extensive volcanic activity and lava flows is termed a dune coast.
8. Submerged, linear sandy structures, seaward of and parallel to the beach are termed barrier islands.
9. Submerged, linear sandy structures, seaward of and parallel to the beach are called bars.
10. Sand spits and hooks are bars isolated from the shore at both ends.
11. Both plants and animals can dramatically modify a coastal area.
12. Terraces formed by the shoreward movement and deposition of materials by waves are termed berms.
13. Beaches are composed entirely of quartz sand.
14. Usually, if we see a beach covered with large particles, i.e., cobbles or gravel, it is considered an eroded beach.
15. Sandy beaches exist at the shore because there is a balance between the rate of supply of sand to the beach and the rate of removal.
16. Waves normally approach the shore with their crests exactly parallel to the shore.
17. The longshore current transports water and sediments down shore in the surf zone.
18. The path that beach sediments travel as they are transported from source to area of deposition is termed a littoral cell.
19. The forces that move particles along the coast are due to high-energy river currents that enter the sea and move down the coast.
20. Most of the United States' wetlands have remained unaltered since colonial times.
21. Wetlands and estuaries are important areas of food, shelter, and reproduction for many species of marine fish.
22. Long-term or severe weather and climate changes may have as disastrous an effect on the well-being, or survival, of estuarine organisms as that of man's activities.
23. Because Chesapeake Bay flushes so slowly, it is less apt to be adversely affected by domestic wastes and pollutants.
24. San Francisco Bay was mainly exploited and altered before 1848, and efforts to increase the bay's health have continued since then.
25. A fjord is a Scandinavian limousine.

MULTIPLE CHOICE

1. Dams well inland from coastal systems can directly affect the coastal zone by
   a. preventing floods.
   b. providing irrigation waters.
   c. causing down current beach erosion by blocking sediment supply to beaches.
   d. creating large reservoirs inland.
   e. none of the above.
2. Before coastal structures are introduced, we should
   a. look at other coastal area where similar structures are in use.
   b. design and test working scale models of the coastal structures.
   c. understand the beach dynamics of the area.
   d. examine the position of the proposed structure within the coastal cell.
   e. all of the above.
3. Average values of coastal sediment transport range from
   a. 150,000 m^3/yr to 1,500,000 m^3/yr.

b. 15,000 m^3/yr to 150,000 m^3/yr.
c. 1500 m^3/yr to 15,000 m^3/yr.
d. 1,500,000 m^3/yr to 15,000,000 m^3/yr.
e. none of the above.

4. Beaches on the down current end of a littoral cell are usually
   a. stable.
   b. eroding.
   c. accreting.
   d. lag deposits.
   e. all of the above.
5. The transport of sediment along the beach is due to
   a. onshore current.
   b. upshore current.
   c. offshore current.
   d. longshore current.
   e. none of the above.
6. Beaches that remain the same over a long period of time
   a. have an input of sediments greater than that of removal.
   b. have an input of sediments less than that of removal.
   c. have an input of sediments exactly balanced by removal.
   d. have no input of sediments, but sediments are slowly being removed.
   e. none of the above.
7. The composition of the sediments on a beach is due to
   a. the composition of the local beach sediments up current.
   b. the river source materials.
   c. the local cliff sediments.
   d. offshore supplies of sand from bars.
   e. all of the above.
8. Offshore bars form primarily in
   a. the summer.
   b. the winter.
   c. shopping malls.
   d. coastal lagoons.
   e. 100s of meters of water.
9. Coastlines formed by marine organisms and their carbonate skeletons are
   a. dune coasts.
   b. lava coasts.
   c. reef coasts.
   d. fault coasts.
   e. all of the above.
10. Coastal sand deposits connected to the shore at one end are called
    a. sand spits and hooks.
    b. barrier islands.
    c. offshore islands.
    d. bars.
    e. reefs.
11. Barrier islands
    a. are extremely fragile ecosystems.
    b. protect the mainland from severe storms.
    c. are constantly moving and eroding.
    d. are poor places for man-made structures.
    e. all of the above.
12. It is estimated that in each second the rivers of the world carry _____ tons of sediment to the sea.
    a. 5.3 tons
    b. 53 tons

c. 530 tons
d. 5300 tons
e. 53,000 tons

13. This erosion rate of land is equivalent to the removal of a layer ____ thick over all of the exposed land above sea level every 1000 yrs.
    a. 0.6 cm
    b. 6 cm
    c. 60 cm
    d. 600 cm
    e. none of the above
14. The two main types of coasts, according to the text are
    a. rocky and reef coasts.
    b. sandy and fault coasts.
    c. primary and secondary coasts.
    d. mud and limestone cliffs.
    e. dune and fault coasts.
15. Coastlines that have been uplifted or experienced previously higher stands of sea level often have
    a. sea stacks.
    b. many rivers.
    c. rocky headlands.
    d. wide, broad bays.
    e. exposed wave-cut terraces.
16. Beaches on the up current end of a littoral cell are usually
    a. stable.
    b. eroding.
    c. accreting.
    d. lag deposits.
    e. all of the above.
17. Beaches in the middle of a littoral cell are usually:
    a. stable
    b. eroding
    c. accreting
    d. lag deposits
    e. all of the above
18. By definition, an estuary
    a. is semi-isolated from the open ocean.
    b. is shallow.
    c. is diluted by fresh water runoff from land.
    d. a and c above.
    e. all of the above.
19. Good examples of __________________ estuaries occur at the mouths of the Mississippi and Columbia rivers.
    a. partially-mixed
    b. salt wedge
    c. well-mixed
    d. fjord-type
    e. estuaries are not found in these locations
20. Vertical profiles of salinity are nearly constant in ______________ estuaries.
    a. partially-mixed
    b. salt wedge
    c. well-mixed
    d. fjord-type
    e. inverse
21. The net flow of water in a _________________ estuary is weak and seaward at all depths.
    a. partially-mixed

b. salt wedge
c. well-mixed
d. fjord-type
e. inverse

22. The degree of vertical mixing in an estuary is influenced by
    a. the strength of tidal currents.
    b. the rate of freshwater addition.
    c. the roughness of the bottom.
    d. the average depth.
    e. all of the above.
23. Inverse estuaries typically have
    a. high evaporation rates.
    b. low evaporation rates.
    c. large tidal prisms.
    d. a rapid influx of seawater at depth.
    e. high precipitation rates.
24. Deep bottom water in a ____________________ estuary can stagnate and become anoxic.
    a. partially-mixed
    b. salt wedge
    c. well-mixed
    d. fjord-type
    e. inverse
25. The volume of an estuary divided by the net seaward flow is a measure of
    a. intertidal volume.
    b. flushing time.
    c. evaporative exchange.
    d. net circulation.
    e. none of the above.
26. If the adjacent ocean salinity is 36 ppt and the average estuary salinity is 27 ppt, what percent of the estuarine water is fresh water?
    a. 30
    b. 15
    c. 20
    d. 12
    e. 25
27. In the United States over _______ % of the population lives within 50 miles of the coastline (including the Great Lakes).
    a. 10
    b. 70
    c. 50
    d. 20
    e. 30
28. The most modified major estuary in the United States is
    a. Puget Sound.
    b. San Francisco Bay.
    c. Mississippi Delta.
    d. Chesapeake Bay.
    e. Long Island Sound.
29. It is estimated that industries and sewage treatment facilities discharge into the Chesapeake an amount of waste water equal to ______ % of the volume of the bay annually.
    a. 5
    b. 10
    c. 15
    d. 20
    e. 25

30. Wetlands bordering estuaries are important as
    a. sources of nutrients.
    b. sources of food.
    c. sources of shelter.
    d. a and b above.
    e. all of the above.

Visual Aids: Test Your Understanding of the Figures

1. Examine figure 12.16 carefully. Think about beaches you have seen or that may even be near where you live. Can you remember seeing any or all of these features? Take a walk on your nearest beach (where possible) and see if your view of a beach has changed.
2. Figure 12.22 is critical to understanding why any structure placed in the beach environment, especially placed perpendicular to the longshore current, will interfere with the longshore transport of fluid and particles. On a separate piece of paper draw a schematic beach (like fig. 12.22) with a groin drawn out into the water. What will happen up current vs. down current of your beach structure?
3. Examine figure 12.2a. From what you have learned about wave refraction, where is wave energy concentrated along coasts such as this one?
4. Look at figure 11.24. Where in the oceanside cell would be the best place for a harbor breakwater or jetty so that it would least affect shoreline processes?

Study Problems

1. Study figure 12.28 and Visual Aid problem number 2. Which side of the structure will experience enhanced erosion?
2. What effect would damming all of the West Coast rivers have on beach erosion?
3. What is the real source of the wave energy reaching the world's beaches?
4. If the salinity of the outward moving surface water of an estuary is 23.7 ppt and the salinity of the inward moving seawater at depth is 34.9 ppt, what fraction of the seaward moving surface layer is river water?
5. If the total rate of river water inflow for the estuary described in problem 4 is 9 unit volumes per unit time, what is the volume rate of seaward flow of the surface layer?

Answer Key for Key Terms and Test Your Recall

KEY TERMS

breakwater (IX)	jetties (IX)	groins (IX)
longshore current (VI)	delta (III)	sand spit (IV)
fjord (III)	moraine(III)	sill (III, XI)
hook (IV)	offshore (VI,VII)	littoral drift (VI)
bar (IV)	backshore (V)	berm (V)
littoral cell (VI)	beach (V)	barrier island (IV)
foreshore (V)	dynamic equilibrium (VI)	salt wedge estuary (XI)
fjord-type estuaries (XI)	water budget (XII)	oceanic input (XII)
inverse estuary (XIII)	intertidal volume (XIV)	estuary (XI)
well-mixed estuary (XI)	net circulation (XII)	river input (XI, XII)
total seaward flow (XII)	partially-mixed estuary (XI)	flushing time (XIV)
sea stack (IV)		

FILL IN THE BLANK

1. coasts	2. beach	3. primary
4. secondary	5. fjord	6. moraine
7. delta	8. sea stacks	9. bars, barrier islands
10. dynamic equilibrium	11. summer, winter	12. longshore current
13. littoral drift	14. rip currents	15. 440,000

16. estuary
17. salt wedge
18. entrainment
19. strong tidal, low river
20. salinity, temperature
21. partially-mixed
22. advection
23. deep, tidal
24. stratification
25. net circulation
26. inflow, outflow
27. salt budget
28. evaporation, precipitation
29. precipitation, evaporation
30. inverse estuaries
31. Red Sea
32. flushing time
33. intertidal volume

TRUE - FALSE
1.F 2.F 3.F 4.T 5.T 6.T 7.F 8.F 9.T 10.F 11.T 12.T 13.F 14.T 15.T 16.F 17.T 18.T 19.F 20.T 21.T 22.T 23.F 24.F 25.F

MULTIPLE CHOICE
1.c 2.e 3.a 4.c 5.d 6.c 7.e 8.b 9.c 10.a 11.e 12.c 13.b 14.c 15.e 16.b 17.a 18.d 19.b 20.c 21.c 22.e 23.a 24.d 25.b 26.e 27.c 28.b 29.d 30.e

STUDY PROBLEMS
1. The down current side will experience enhanced erosion.
2. This will accelerate beach erosion, as sediment supply will be severely reduced.
3. Solar energy.
4. 32%
5. 28 unit volumes per unit time