CE/SC 10110-20110: Planet Earth

Oceans & Coasts

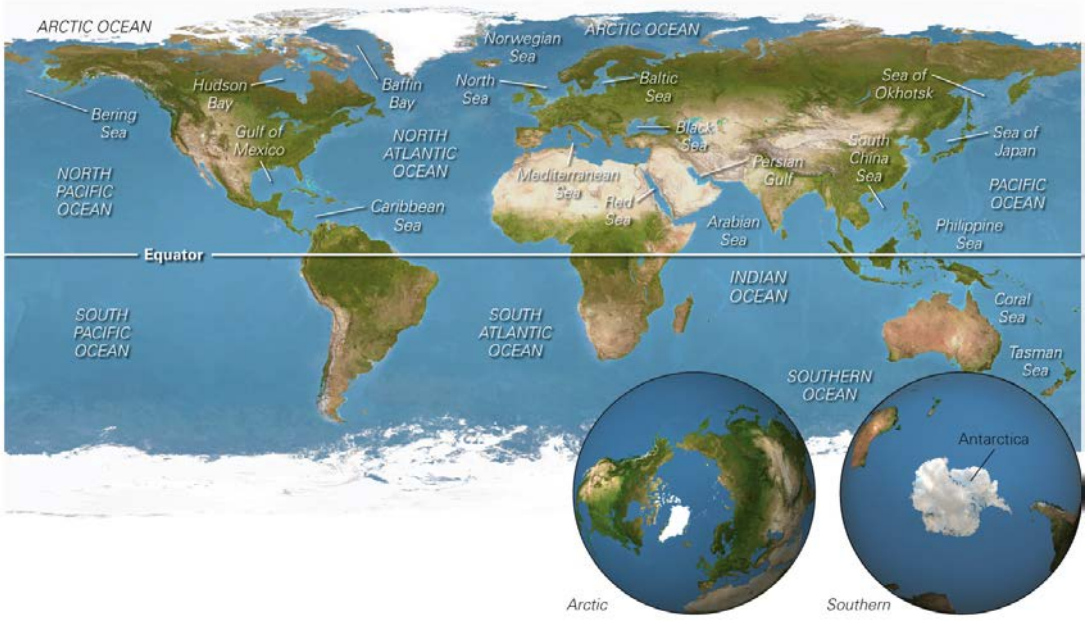
Earth

Portrait of a Planet
Fifth Edition

Chapter 18

Coast: Where land and sea meet. Over 60% of the worlds population lives along coasts.

Earth's Oceans



The Sea Floor

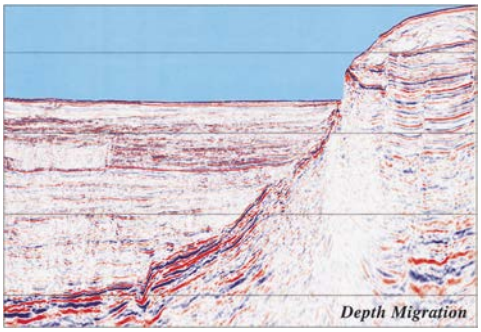
Oceans = 70.8% of the Earth's surface.

Northern hemisphere: 60% ocean, 40% continent
Southern hemisphere: 83% ocean, 17% continent.

Oceanography: scientific study of the oceans (e.g., topography of the ocean floor, compositions of the oceans, currents, asthenosphere-ocean interactions, etc.)

Oceans are the basis for life on Earth. They regulate climate, cycle mass, and energy. Around 60% of humans live near coasts.

Landscapes Beneath the Sea

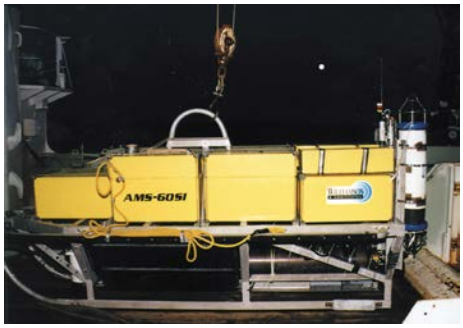


Ocean depth, or bathymetry, variations can be measured using sonar.
Sub-seafloor structure can be imaged via seismic reflection.

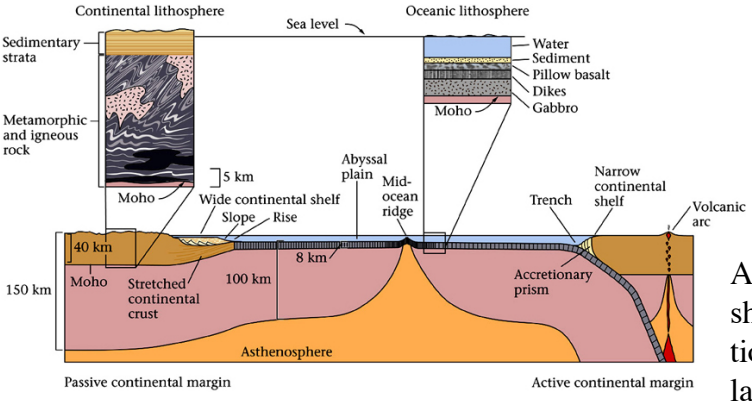
Oceanic crust forms ocean basins as it is relatively more dense than continental crust.

Ocean floor investigated using submersibles, either manned or remotely operated.

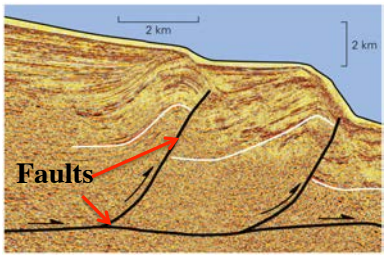
Sub-seafloor sampling via drilling from JOIDES Resolution, Chikyu drill ships.



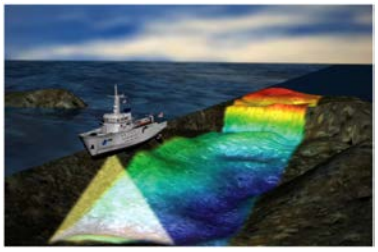
Landscapes Beneath the Sea



Continental margins divided into "active" and "passive". Each margin has a continental shelf, continental slope. Active margins are compressed relative to passive margins and also contain an oceanic trench. The abyssal plain extends into the ocean basin.



A seismic reflection profile shows the structure of an accretionary prism and sediment layers of the Pacific floor



Aleutian trench, south of Alaska

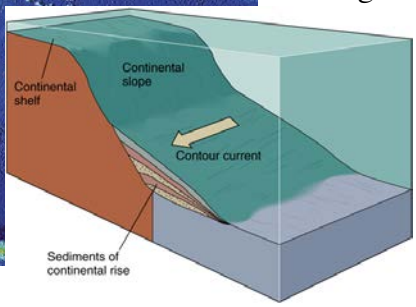
Landscapes Beneath the Sea

Sediments washed off the continents + biogenic material accumulates on the continental shelf and can build up to 20 km thick on passive margins.

The continental slope on active margins is the face of the accretionary prism.

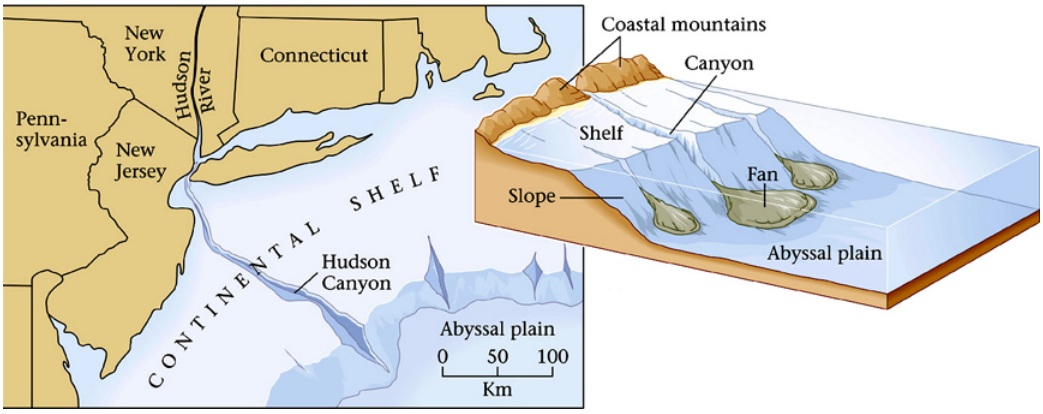
Passive Margin

…pe is ~2° on passive …ive margins.



Contour Currents: run parallel to the continental slope, not down it (follow the contours).

Landscapes Beneath the Sea



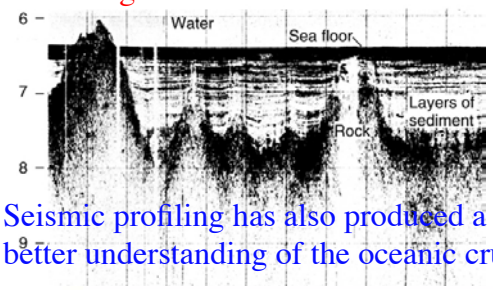
Submarine canyons often form offshore from rivers. This may be because the channel may have been cut by the river when sea level was lower.

Most erosion is caused on the ocean floor by turbidity currents. Deposits form ***submarine fans*** on the abyssal plains.

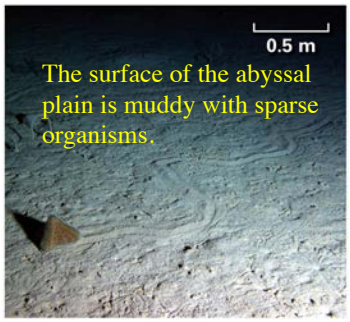
Ocean Basin Floor

Abyssal Plains: flat seafloor in deep water beyond the continental slope. Depth: 4,000 – 6,000 meters.

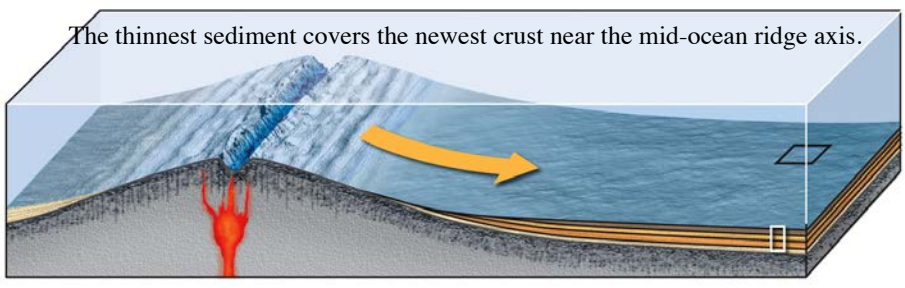
Flattest place on earth – topology of the oceanic crust is fairly irregular, but sediments fill in the irregularities, resulting in "mud-flats".



Seismic profiling has also produced a much better understanding of the oceanic crust.



Abyssal plain strata are horizontally bedded



Ocean Basin Floor

Sediments = fine ***pelagic*** deposits.

Pelagic sediment – settles slowly through the ocean water and is made up of fine-grained clay and the skeletons of microscopic organisms.

Includes muds – clay, silt from the continents, accumulated ***oozes*** (from skeletal remains of the microscopic organisms), shale, and chert.

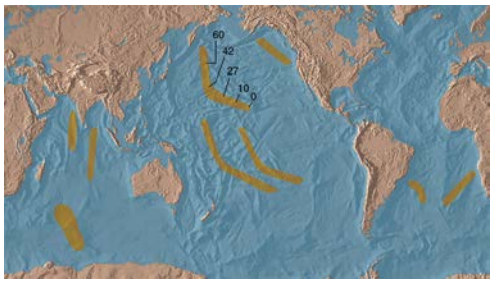
Ocean Basin Floor

Volcanic features are common:

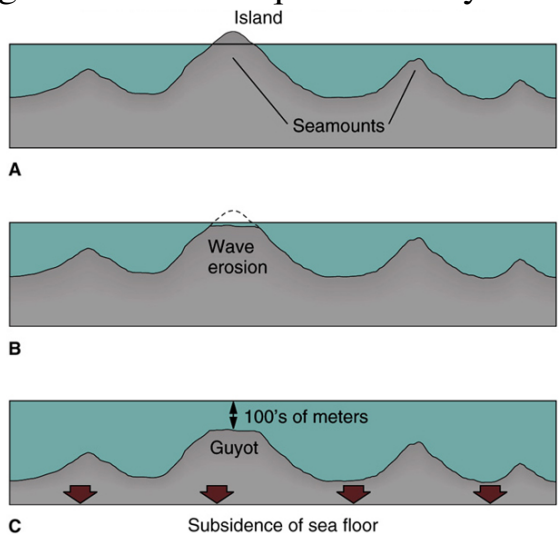
Abyssal Hills can be up to 1,000 meters high.

Seamounts: steep sided volcanoes that rise abruptly from the seafloor, sometimes forming islands.

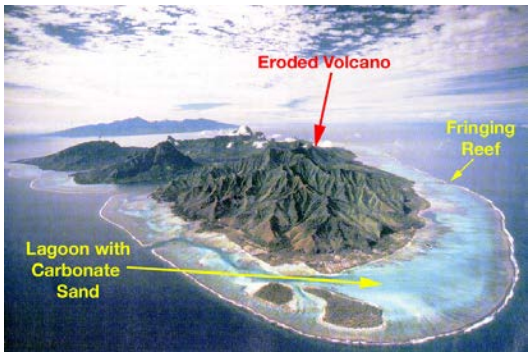
Aseismic Ridges: submarine ridges with no earthquake activity – aligned seamounts or guyots.



Guyot: submerged flat-topped seamount 1,000 – 1,700 meters below the surface.



Coral Reefs

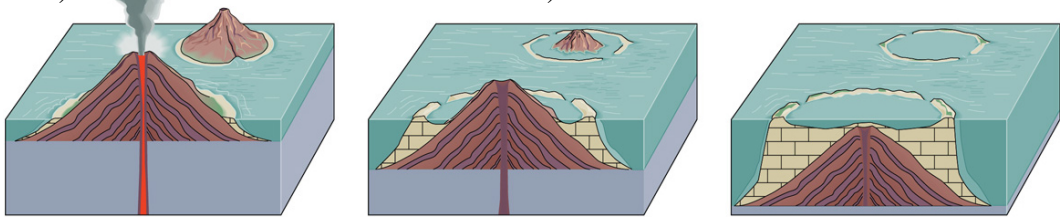


In warm water, coral reefs associated with seamount → sunlight, shallow warm water, seamount provides the anchor.

Fringing Reefs: flat, table-like reefs attached directly to the shore. The seaward edge is marked by a steep slope down into deeper water (e.g., around the Hawaiian Islands).

Barrier Reefs: parallel to the shore, but separated from it by wide deep lagoons. The lagoon has quiet waters as the reef protects it (e.g., Great Barrier Reef).

Atolls: circular reefs that rim lagoons and are surrounded by deep water. Small wave-built islands of calcareous sand at places along the reef ring (e.g., Bikini Atoll).



Coral Reefs

Coral reefs develop 0°-30° latitude. Coral polyps secrete $CaCO_3$ shells. Need clear, well lit, warm (18°-30°) water with normal salinity.

Occur along coasts and around seamounts at <30°

Seawater Composition

Chloride	**Cl^-**	**19.35%**
Sodium	**Na^+**	**10.76%**
Sulfate	**SO_4^{2-}**	**2.71%**
Magnesium	**Mg^{2+}**	**1.29%**
Calcium	**Ca^{2+}**	**0.41%**
Potassium	**K^+**	**0.39%**
Bicarbonate	**HCO^{2-}**	**0.14%**
Bromide	**Br^-**	**0.067%**

Everything Else < 0.01

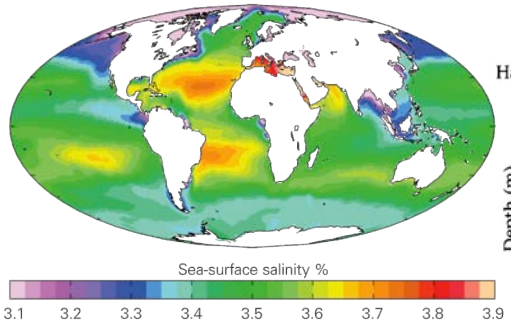
Total Dissolved Solids ~ 30-41%

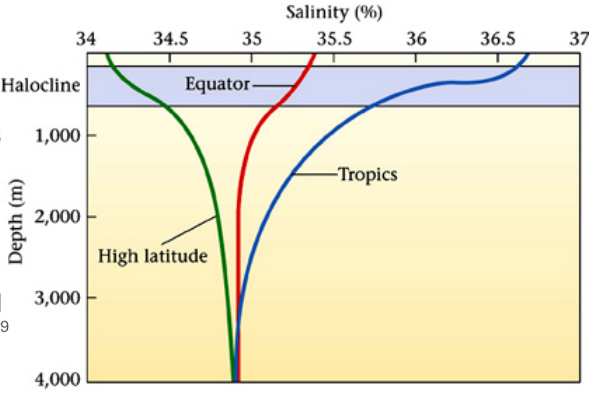
Seawater is more dense than freshwater because of the dissolved ions.

These ions are products of chemical weathering of rocks and transported to the sea via rivers.

Salinity varies with latitude and depth.

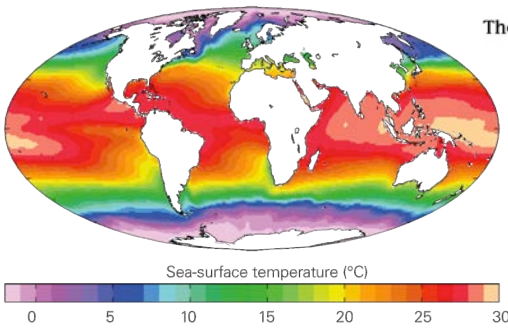
Halocline: gradational boundary between surface-water salinities and deep-water salinities.

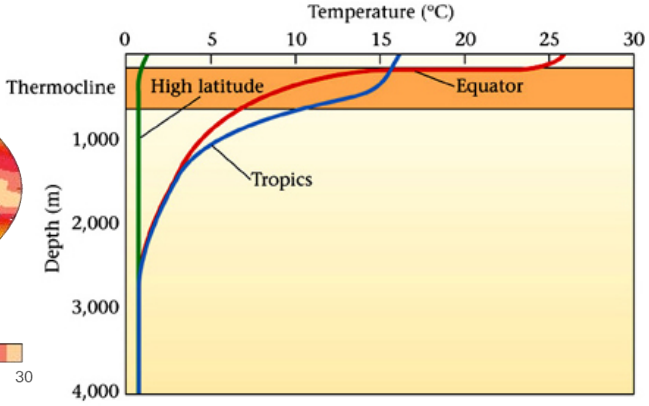




Seawater Temperature

Like salinity, seawater temperature varies with latitude and depth.

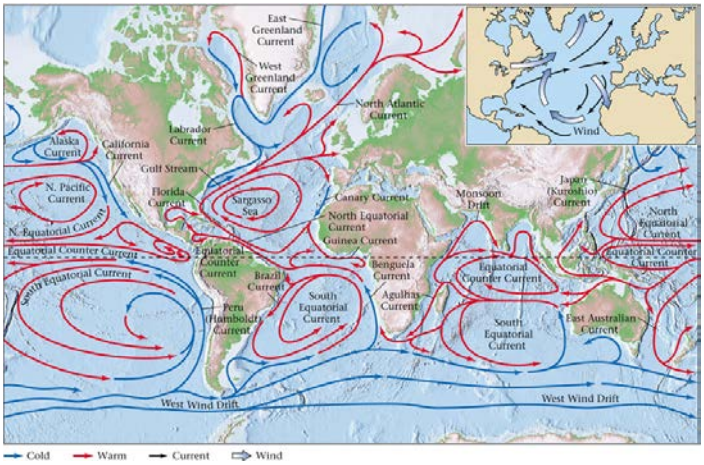




Thermocline: depth below which water temperature decreases abruptly.

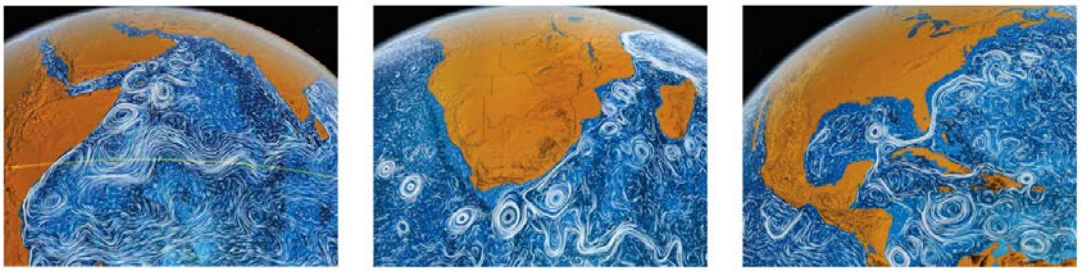
Water can hold and release large amounts of heat without changing temperature very much - it regulates temperatures of coastal regions.

Surface Currents

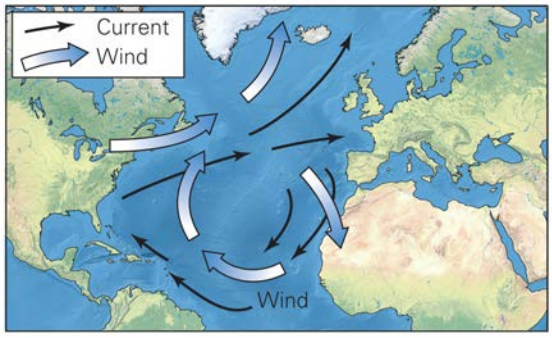


Formed by interaction of the sea with the atmosphere - subject to the Coriolis Effect. Clockwise in the N. Hemisphere, counterclockwise in the S. Hemisphere.

Circular flow patterns = ***gyres***. Water at the center is isolated from the surface currents. The position of the continents affects the circulation - could cut off the circulation of warm water to the poles.

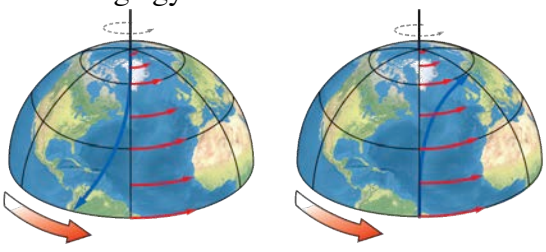


The Coriolis Effect



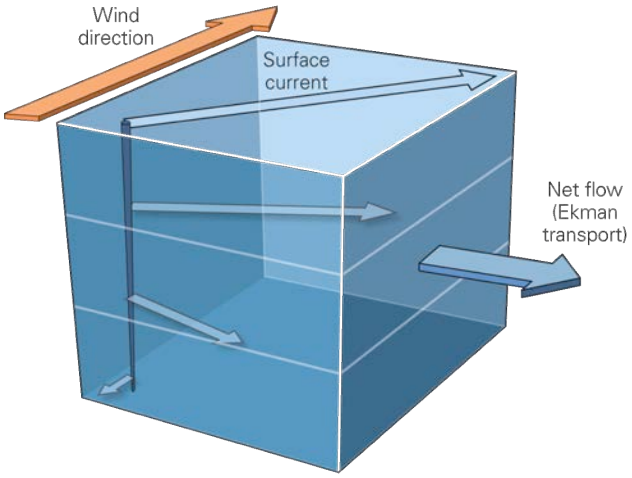
Rotation deflects prevailing winds and currents. The sense of deflection depends upon the initial direction of motion and the position relative to the equator.

The velocity of a point at the equator, in the direction of the Earth's spin, is greater than that of a point near the pole. Due to the Coriolis effect, currents deflect clockwise, relative to the wind in the northern hemisphere. Currents spiral by Coriolis deflection into large gyres.



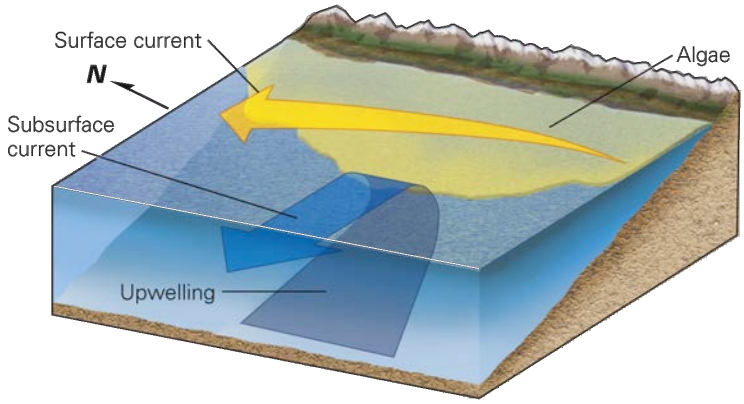
A projectile shot from the North Pole to the equator deflects to the west. Winds and currents moving north to south are likewise deflected west. A projectile shot from the equator to the North Pole deflects to the east. Winds and currents moving from south to north are likewise deflected to the east. Southern hemisphere is a mirror image.

Ekman Transport

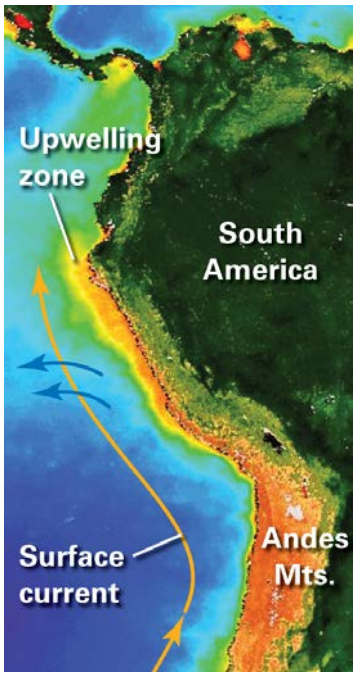


Oceans = series of layers, each shearing the layer below. The Coriolis effect deflects the successive deeper layers 45° to the one above. Form the ***Ekman Spiral***.
Net water transport of water in the upper 100 m is 90° to the wind direction

Upwelling and Downwelling



An offshore wind pushes water away from the shore. The water must be replaced and it is, by water pulled up from the depths—upwelling. Northerly winds produce an offshore Ekman transport, which drives upwelling of nutrient-rich bottom waters. Upwelling coastal margins have high rates of biological productivity.



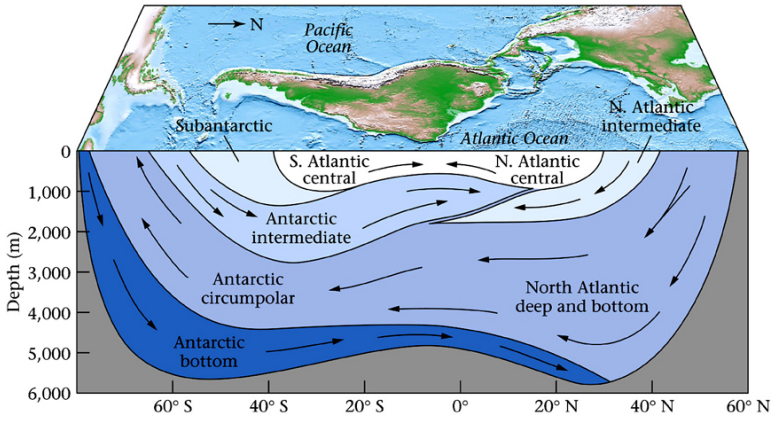
Ocean Circulation

Causes of upwelling/downwelling:

Surface Winds: pile water up at coasts - excess water sinks. If winds blow water away from coasts, water rises up to take the place of the surface water.

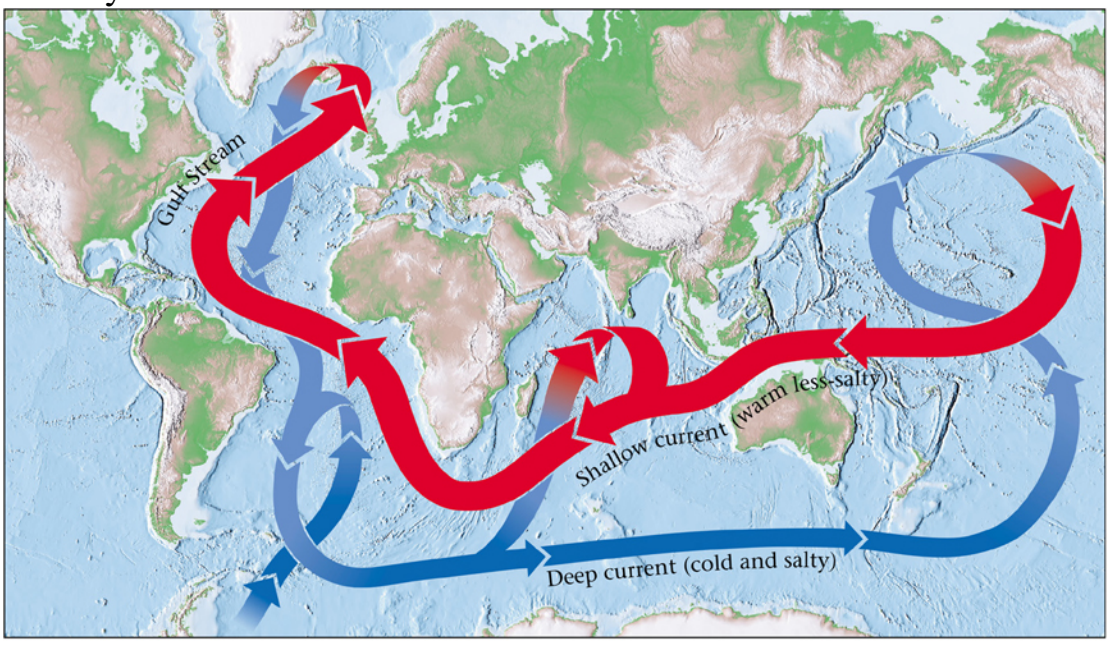
Upwelling occurs at the equator because winds blow east to west and cold water wells up to replace the warm surface water.

Thermohaline Circulation: circulation due to density contrasts. Water in polar regions sinks (cold/more salty); water that is warmer/less salty rises.



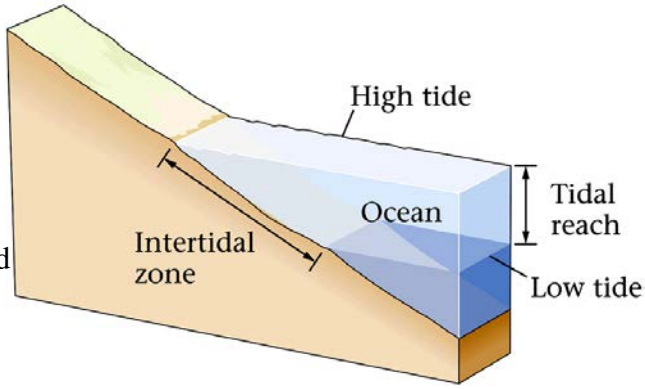
Ocean Circulation

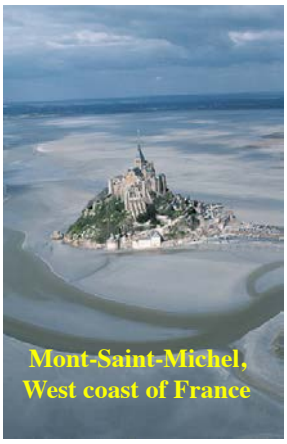
Combination of surface and deep water circulation produces a conveyor belt of ocean circulation.



Tides

Tide: vertical movement of sea level.
Tidal Reach: difference between high and low tides.
Intertidal Zone: area covered at high tide and exposed at low tide.
Tidal Flat: if slope is gentle, a broad flat area is exposed at low tide.




Mont-Saint-Michel, West coast of France

Tides are actually shallow water waves and depend heavily upon topography.

2 high tides (= flood tides) and 2 low tides (= ebb tides) each day.

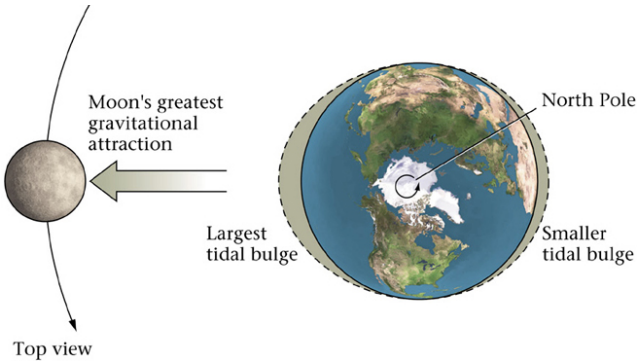
Flood tides can produce a wall of water (cm to m in height) = **Tidal Bore**.

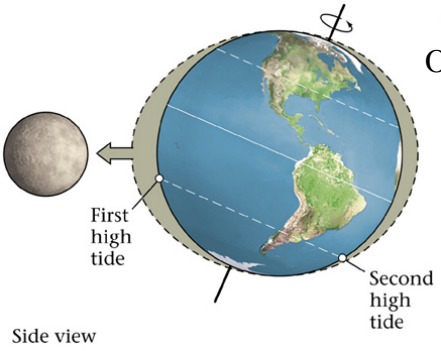
Tides

Tides

Tides result from the gravitational attractions of the Moon and Sun acting on the rotating Earth. Main tidal forces caused by the Moon. Variability: 0.1 – 15 m.

Tidal bulges produced where Moon's gravity is strongest (closest to the Moon and weakest (furthest from the Moon) where centrifugal force of Earth's rotation pushes water out.



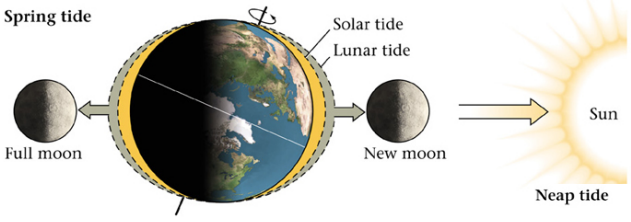


Other factors affecting time and magnitude of tides:

Tilt of Earth's Axis: this is not perpendicular to the plane of the Earth-Moon system. A given point passes through a high part of one bulge during one part of the day and a lower part of the other bulge during another part of the day - the two high tides are not of the same magnitude.

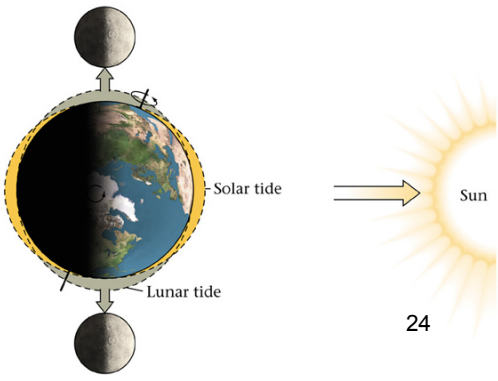
Tides

The Moon's Orbit: Earth rotates every 24 hours on its axis. Moon orbits the Earth every 29.5 days: 360°/29.5 = 12.2°/day movement of the Moon. Therefore, it takes the Earth (12.2/360) X 24 ~ 50 minutes extra to catch up so the "Tidal Day" is 24 hours and 50 minutes.



Sun's Gravity: If Moon and Sun are aligned, tides are higher (**Spring Tides**).

If they are at 90°, tides are lower (**Neap Tides**).



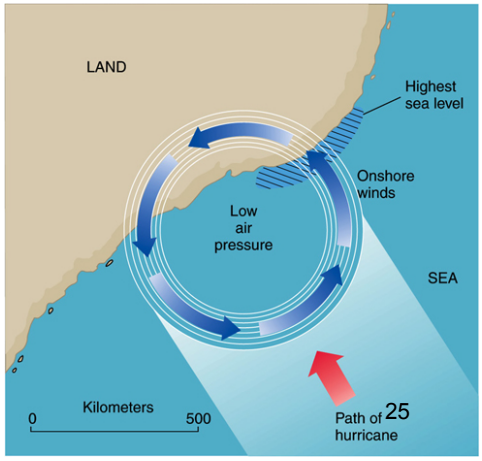
Tides

Focusing Effect of Bays: In the open ocean, tidal reach is only a few meters, but a bay that narrows to a point brigs a large volume of water into a small area - Bay of Fundy, Canada, has a 20 m tidal reach.

Basin Shape: This can influence wave motion, which can reinforce waves to increase the tidal reach, or cancel out waves to decrease the tidal reach.

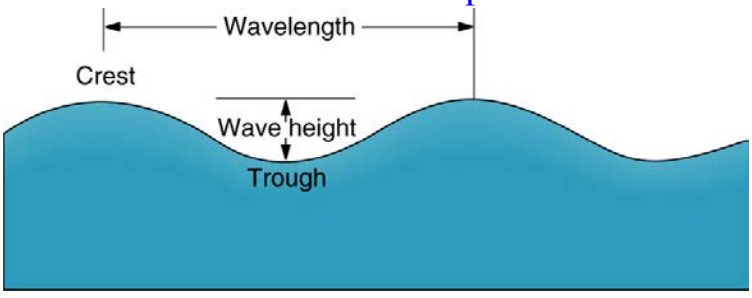
Air Pressure: Storm surge can push high tides higher (e.g., hurricanes).

Friction between ocean and basin cause the tidal bulge to lag slightly behind the movement of the Moon. Causes the Earth's rotation to slow down - days are growing longer by 0.002 seconds per century!



Wave Action

Most waves are generated by wind - size depends on persistency of wind direction, wind velocity, and the distance ("fetch") over which it blows. Can create swells up to 35 m.



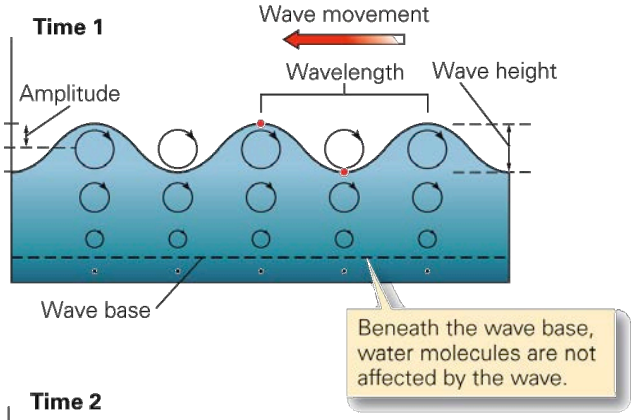
Period: time required for two successive crests or two successive troughs to pass a point in space.

Wavelength (L): the distance between adjacent points on a wave that are in phase (i.e., moving in the same direction & displaced the same distance from the undisturbed water level).

Wave Base: depth below which waves have no effect on water circulation. The is commonly half of the wavelength (L/2).

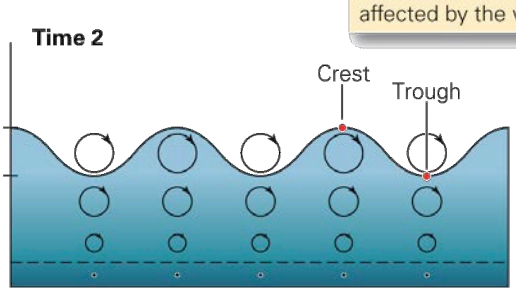
Wave Action

Wave motion: water is moving in an orbit, wave propagation is moving energy forward, <u>not</u> the water mass.

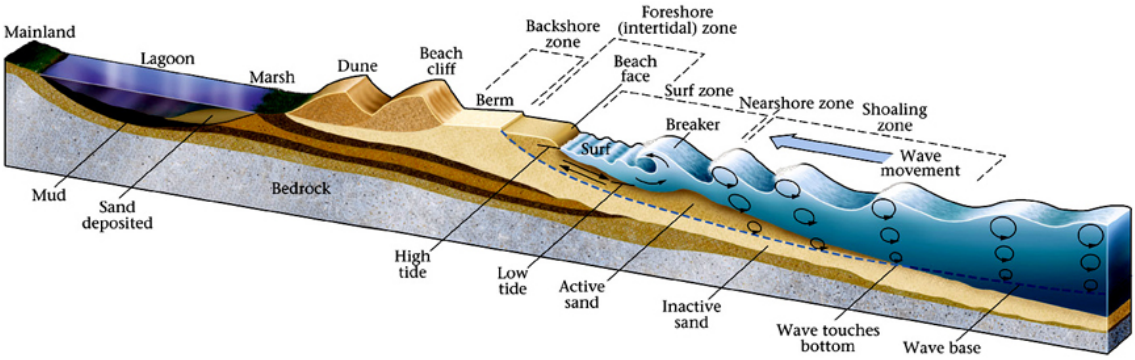


As wave propagates, particles move in an orbit and return to roughly the same place (objects bob up and down).

Waves "feel" only down to L/2. Waves in water where D > L/2 = deep water waves and are unaffected by ocean floor topography. D = depth.



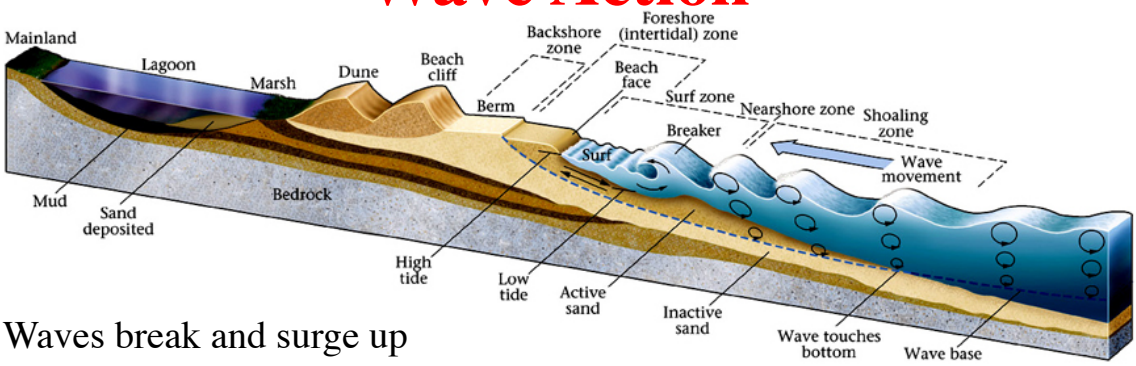
Wave Action



Waves in water with depth D < L/2 = shallow water waves and these feel the bottom topography:

- Wave orbits are forced to become elliptical;
- Wave energy is confined to shallower depths, it builds up and breaks in the surf zone;
- Waves slow down once they start to "feel" sea floor.

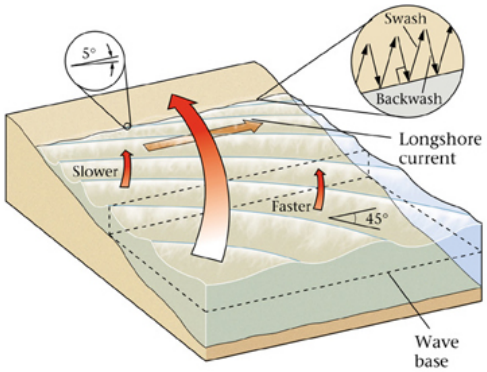
Wave Action



Waves break and surge up the beach = **Swash**.

Backwash = retreat of water back down the beach.

Wave refraction occurs where the wave enters the shallow water obliquely.



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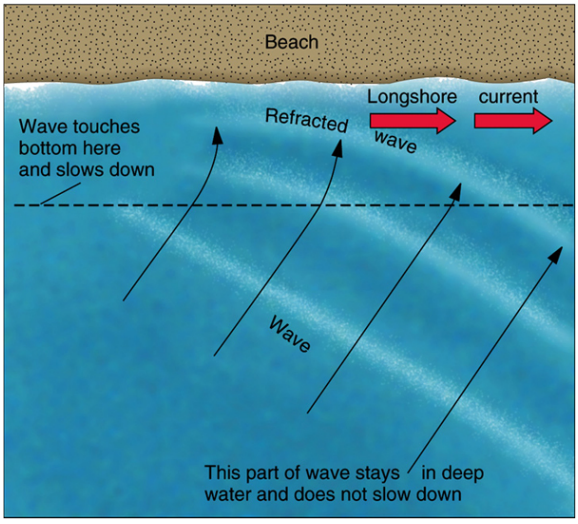
Wave Action

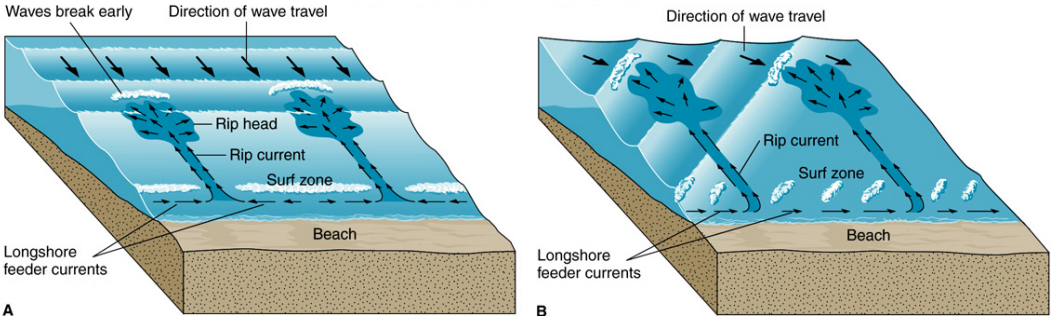
Refraction of waves produces ***longshore currents*** - movement parallel to shore when the waves strike the shore obliquely due to prevailing winds. Produces **longshore drift**.



30

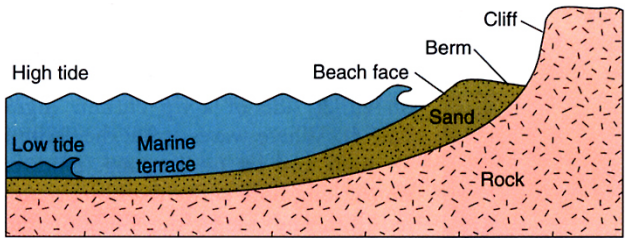
Wave Action

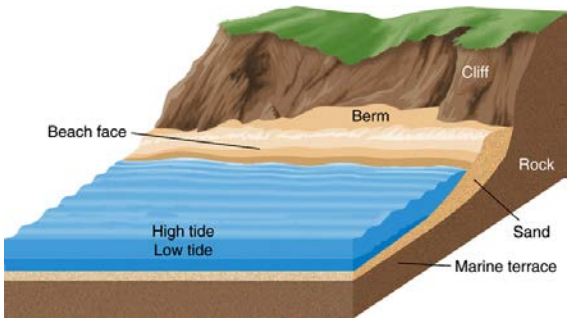
Undertow – return of water along sea floor.
Rip Currents - localized undertow.

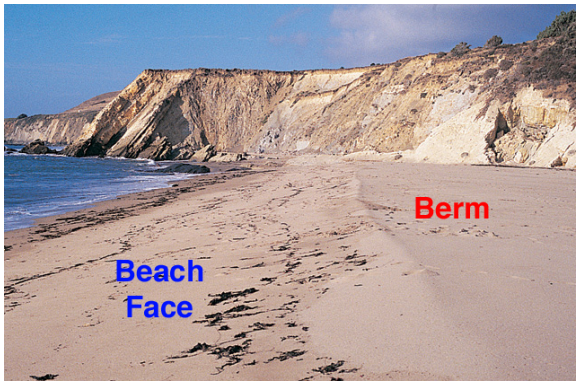


Beaches & Tidal Flats

Beaches - deposits from erosion and movement of sediment.
Beach: strip of sediment that extends from the low-water line inland to a cliff or zone of permanent vegetation.
(a) Beach Face: steepest part of the beach.
(b) Berm: wave-deposited platform that is nearly flat – deposited above the usual high water line due to storms.

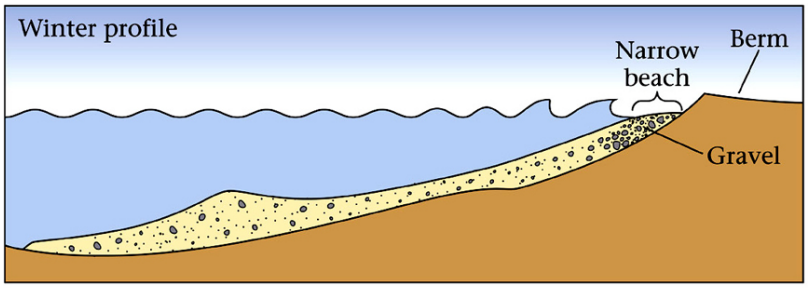




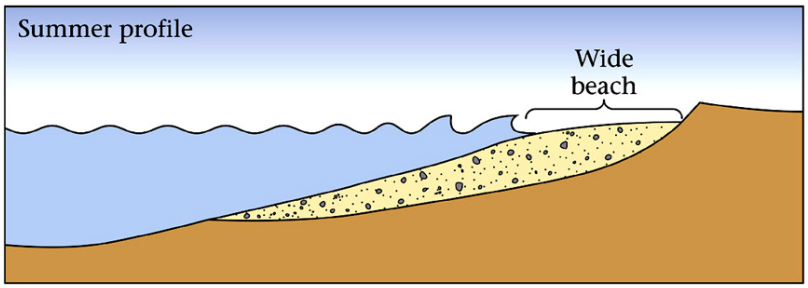


Beaches & Tidal Flats

Annual Cycles



(a)



(b)

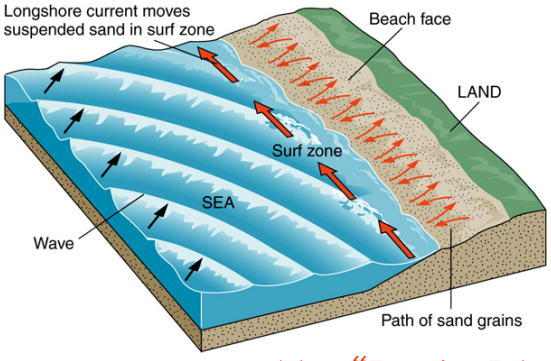
Beach Composition

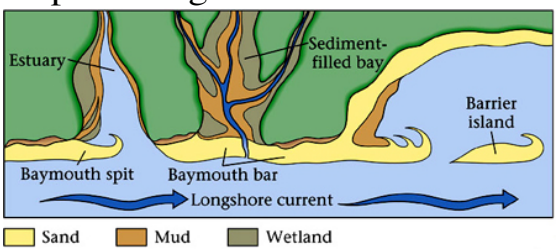
Beach sand composition is determined by the local geology. They are usually made of resistant minerals, especially quartz. Carbonate grains abound in tropical settings.

Beaches & Tidal Flats

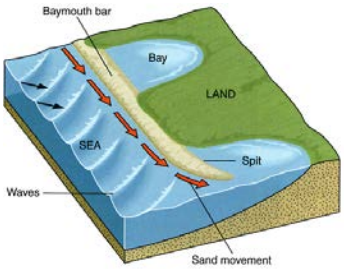
Beaches are "moved" by longshore drift producing "Beach Drift".

Spits and ***Baymouth Bars*** produced.

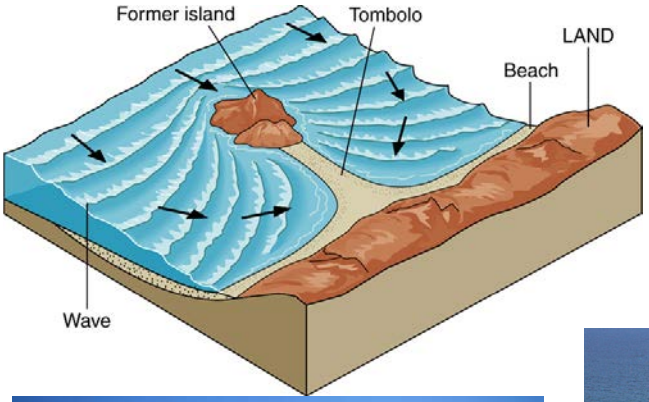




Also "Barrier Islands"



Beaches & Tidal Flats

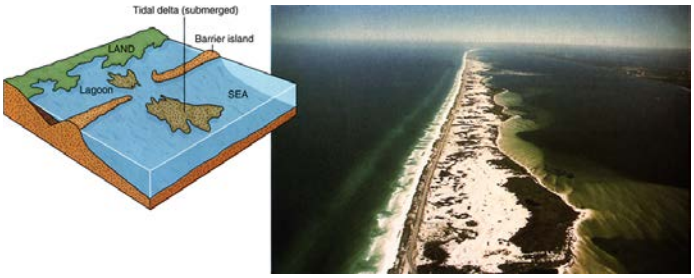


Waves refract around an island and can cause sediment transported by longshore currents to form a **Tombolo** or land link to the island.

Beaches & Tidal Flats

Barrier Islands

Scouring action of waves piles sand up offshore in a narrow ridge.
Lagoon = quiet water between the barrier island and shore.



Barrier Islands are continually modified by longshore drift and storm surges. NOT good to live on!

Barrier Islands

Waves sculpt sand into elongate offshore bars parallel to the shoreline. In regions with abundant sand, offshore bars can rise above sea level to become barrier islands. Barrier islands protect a shallow, quiet-water lagoon that accumulates mud.

Tidal Flats

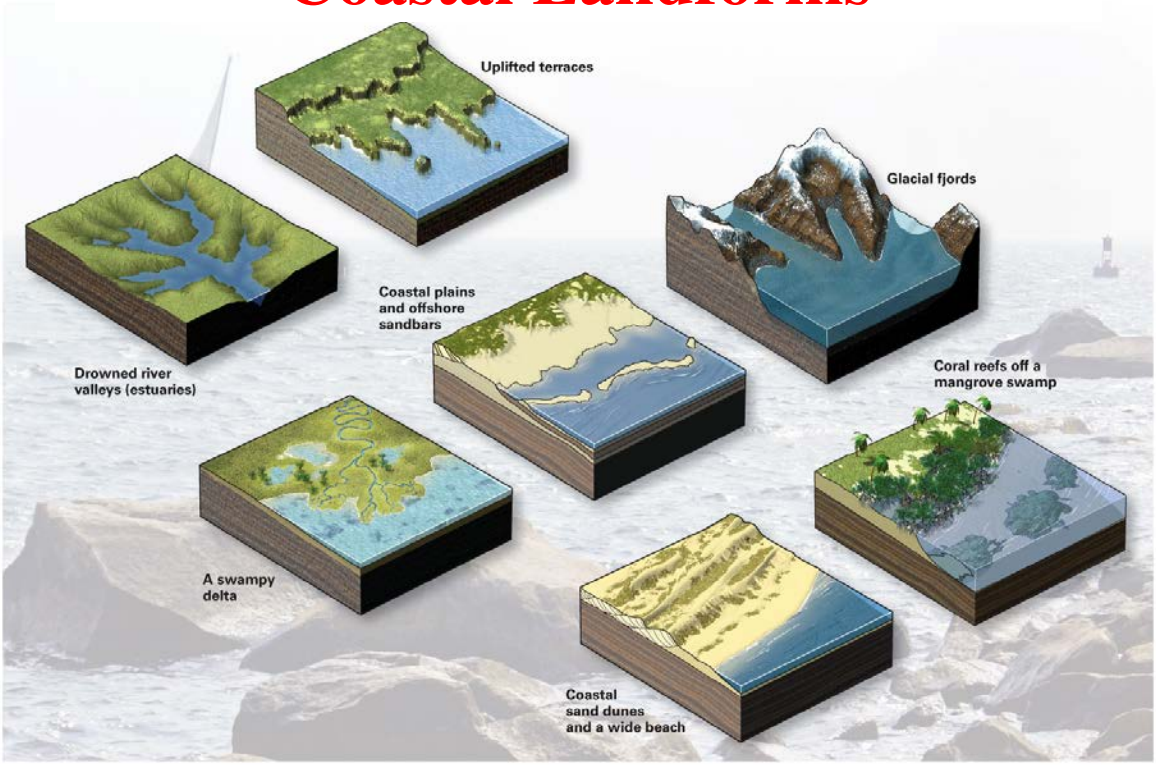
Tidal flats are intertidal regions that accumulate mud and silt to form thick, sticky mud deposits. Tidal flats display bioturbation, abundant sediment reworking by burrowing organisms.

Beaches & Tidal Flats

Tidal Flats

Flat areas of mud/silt exposed at low tide, but covered at high tide.
Develop where protected from strong wave action (i.e., behind barrier islands).
Mud and silt deposited in layers, but mixed by bioturbation (worms, clams, etc.).

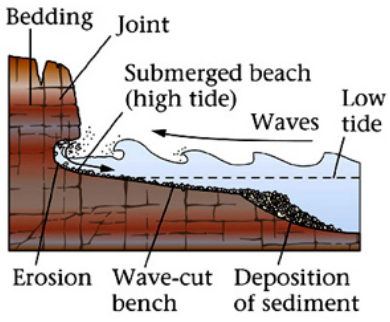
Coastal Landforms



Rocky Coasts

Waves undermine cliffs, initially forming a ***wave-cut notch***.

Continued wave action produces a ***wave-cut bench*** or ***wave-cut platform***.

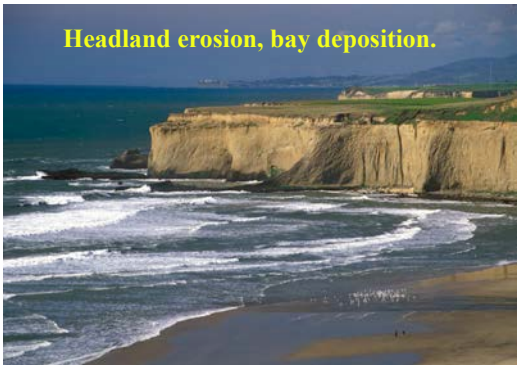


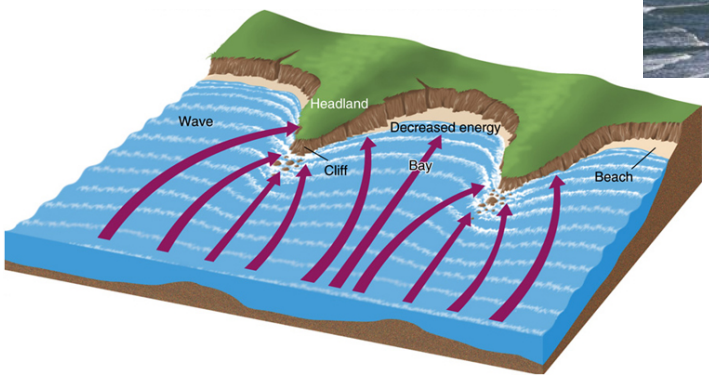
Rocky Coasts

Coasts eroded by waves via:

(i) Hydraulic action by compression of air in joints/cracks/planes of weakness;

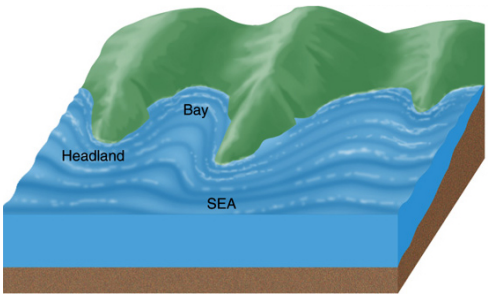
(ii) Abrasion – movement of fine particles.

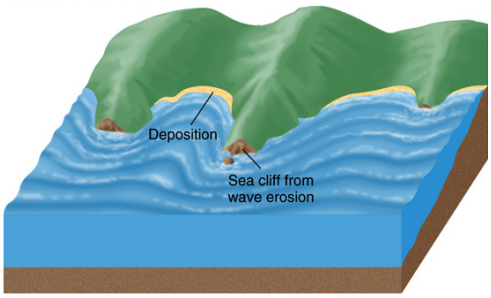




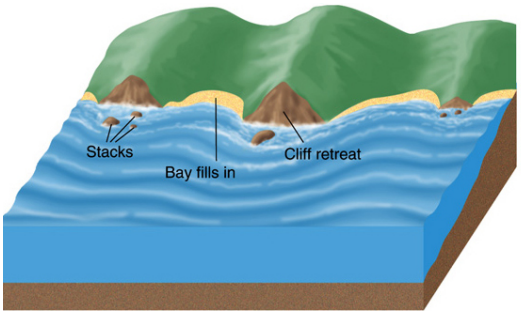
Wave action tends to focus energy on cliffs and results in the erosion of **Headlands** via **Wave Refraction**. Deposition in bays.

Rocky Coasts

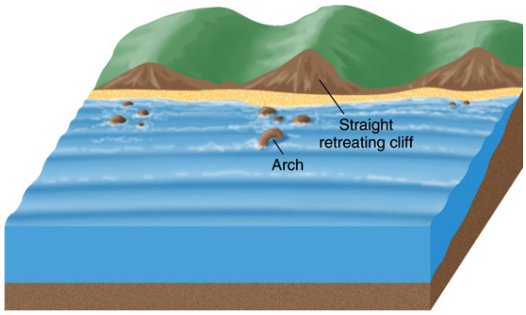




Stage 1: Flooding of coast results in an irregular coast.



Stage 2: Erosion of cliffs/headlands.

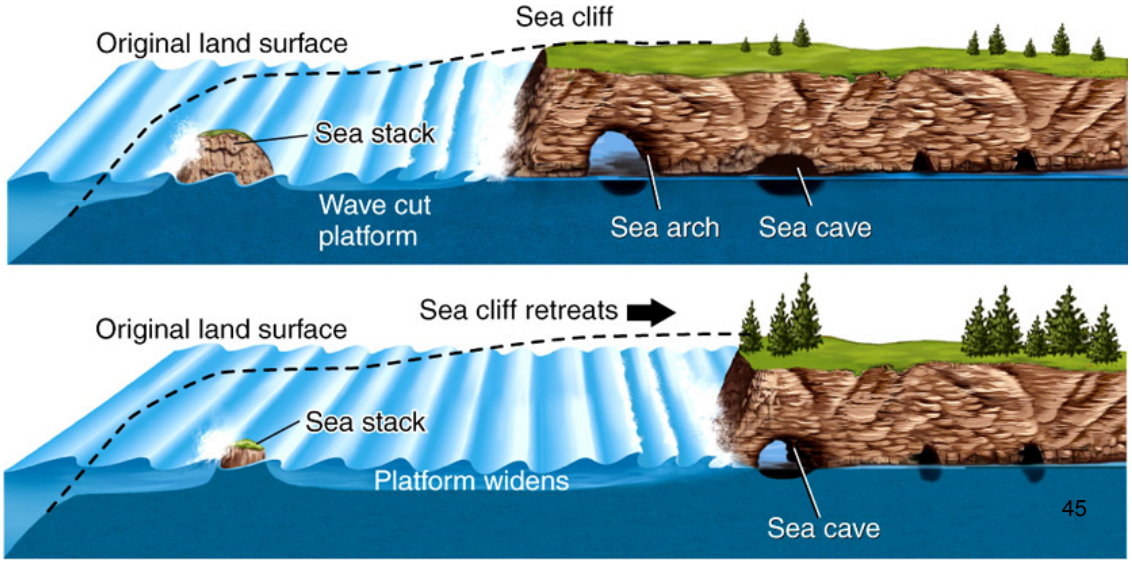


Stage 3: Straightening of beach.

Rocky Coasts

Stack = isolated, pillar-like island detached from headland by wave erosion (i.e., erosional remnant of a headland).

Wave action tends to downcut, creating a **Wave-Cut Platform** terminated by a cliff. The cliff then retreats with time.



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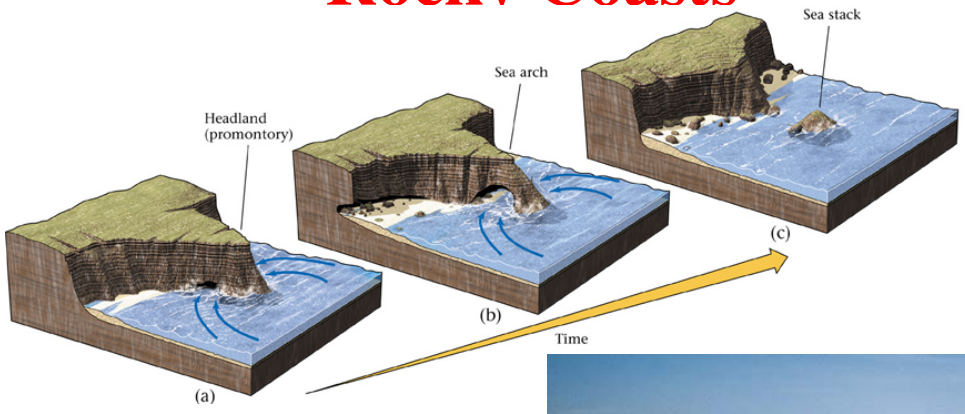
Rocky Coasts



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Coastal Wetlands

Vegetated, flat-lying stretch of coast that floods with tides, but does not experience wave action.

Temperate climates: ***swamps*** (wetlands dominated by trees); ***marshes*** (wetlands dominated by grasses); ***bogs*** (wetlands dominated by moss and shrubs).

Tropical/semitropical climates: ***mangrove swamps*** - mangrove trees survive in fresh and salt water because their roots can filter out salt.

Submergent/Emergent Coasts

Sea-level change can be global (eustatic sea-level change) or local.

Eustatic sea-level changes caused by:

Changes in volume of mid-ocean ridges;
Glaciation/deglaciation.

Produce submergent (drowned) coasts and emergent coasts.

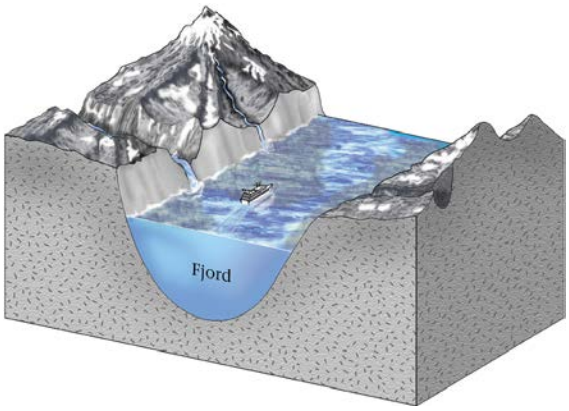
Local sea-level changes can be produced by tectonic uplift along a subduction zone or local isostatic rebound.

Submergent/Emergent Coasts

Submergent coasts:

Estuary: Drowned river valley. Protected from wave action - water becomes stratified. Denser salt water beneath freshwater. Mixing = ***brackish*** water.

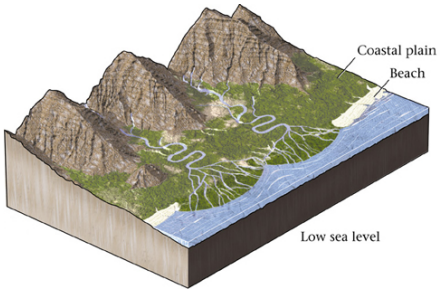
Fjord: Drowned U-shaped (glaciated) valley.

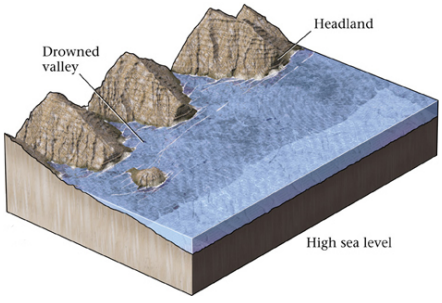


Submergent/Emergent Coasts

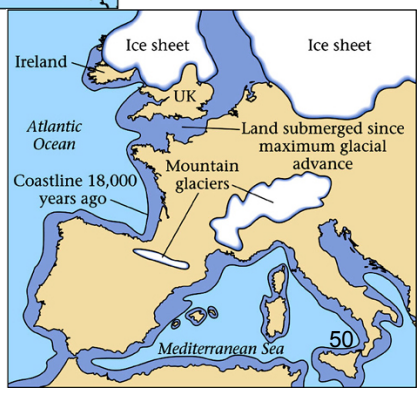
Submergent coasts:

Headland and bay development.

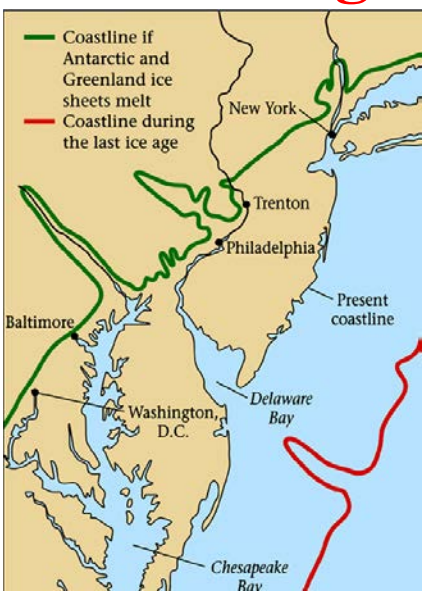




Coasts submergent after last ice age

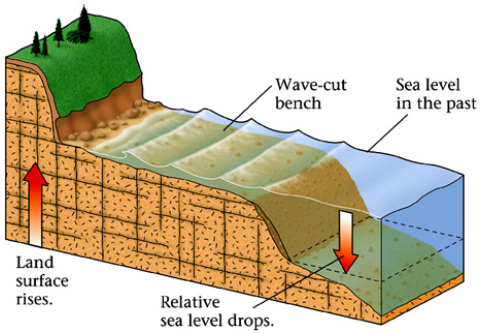


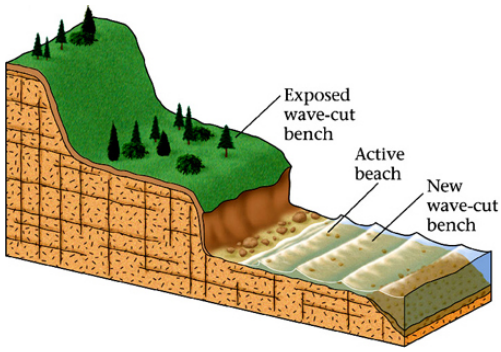
Submergent/Emergent Coasts



If global warming melts all the ice……

Emergent Coasts





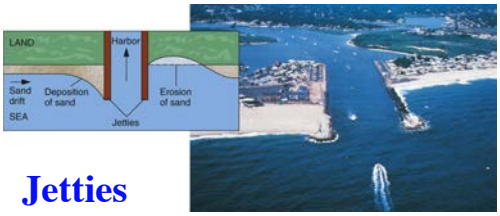
Submergent/Emergent Coasts

Emergent Coasts

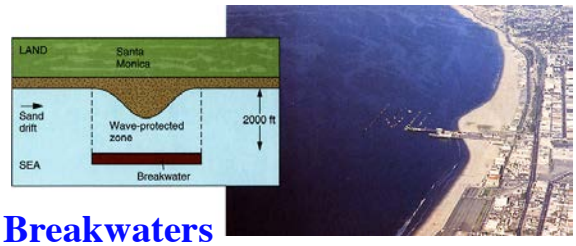
Sea-level falls:
Waves break offshore.
Get barriers, bars, and lagoons forming.
Lagoons fill with sediment from streams.
Beach propagates seaward.

Beach Protection

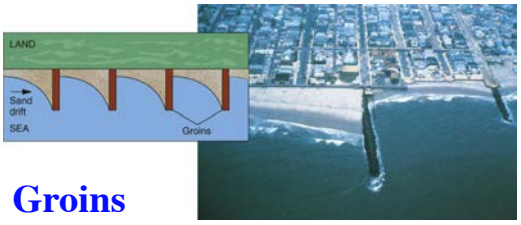
Stop beaches migrating/eroding. Prevent cliff erosion. Protect property values.



Jetties



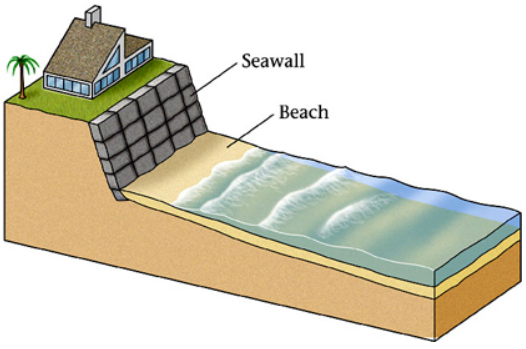
Breakwaters

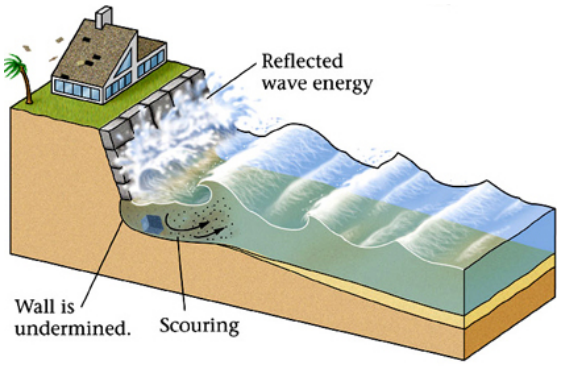


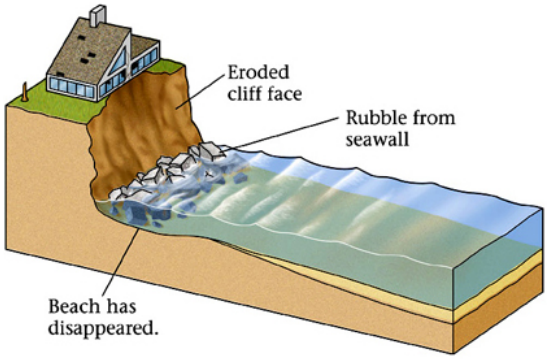
Groins

Beachfront flyover.mov

Beach Protection







Big storms/hurricanes can overwhelm defenses.

Summary

Oceans: Bathymetry; Drilling; Seismic Reflection; Passive and Active Margins; Abyssal Plain; Continental Shelf & Slope; Oceanic Trench; Mid-Ocean Ridge; Contour Currents; Submarine Canyons; Submarine Fans; Pelagic Sediment; Abyssal Hills; Seamounts; Aseismic Ridges; Guyots.

Coral Reefs: Fringing; Barrier; Atolls; Coastal.

Seawater Composition: Halocline; Thermocline.

Surface Currents & Ocean Circulation: Coriolis Effect; Gyres; Surface Winds; Thermohaline Circulation.

Tides: Tides; Tidal Reach; Intertidal Zone; Tidal Bore; Tidal Flat; Tidal Bulge; Influence of the Moon & Sun; Tilt of Earth;' s Rotational Axis; Moon' s Orbit; Focusing Effect of Bays; Basin Shape; Air Pressure; Tidal Friction.

Summary

Wave Action: Fetch; Period; Wavelength; Wave Base; Wave Motion; Breaker; Swash; Backwash; Wave Refraction; Longshore Current; Longshore Drift; Undertow; Rip Currents.

Beaches & Tidal Flats: Beach; Beach Face; Berm; Annual Cycles; Beach Drift; Baymouth Bars; Spits; Tombolo; Barrier Islands & Lagoons; Tidal Flats.

Rocky Coasts: Wave-cut Notch; Wave-cut Platform (or Bench); Erosion by Hydraulic Action, Abrasion; Headland Erosion; Stacks;

Coastal Wetlands: Temperate Climates (Swamps, Marshes, Bogs); Tropical/ Semitropical (Mangrove).

Submergent/Emergent Coasts: Eustatic Sea-Level Changes (changes in mid-ocean ridge volume; Glaciation/Deglaciation); Submergent Coasts (Estuary; Fjords; Headlands & Bays); Emergent Coasts Raised Wave-cut Platforms.

Beach Protection: Jetties; Breakwaters; Seawalls; Groins.