

Why Study Shorelines?

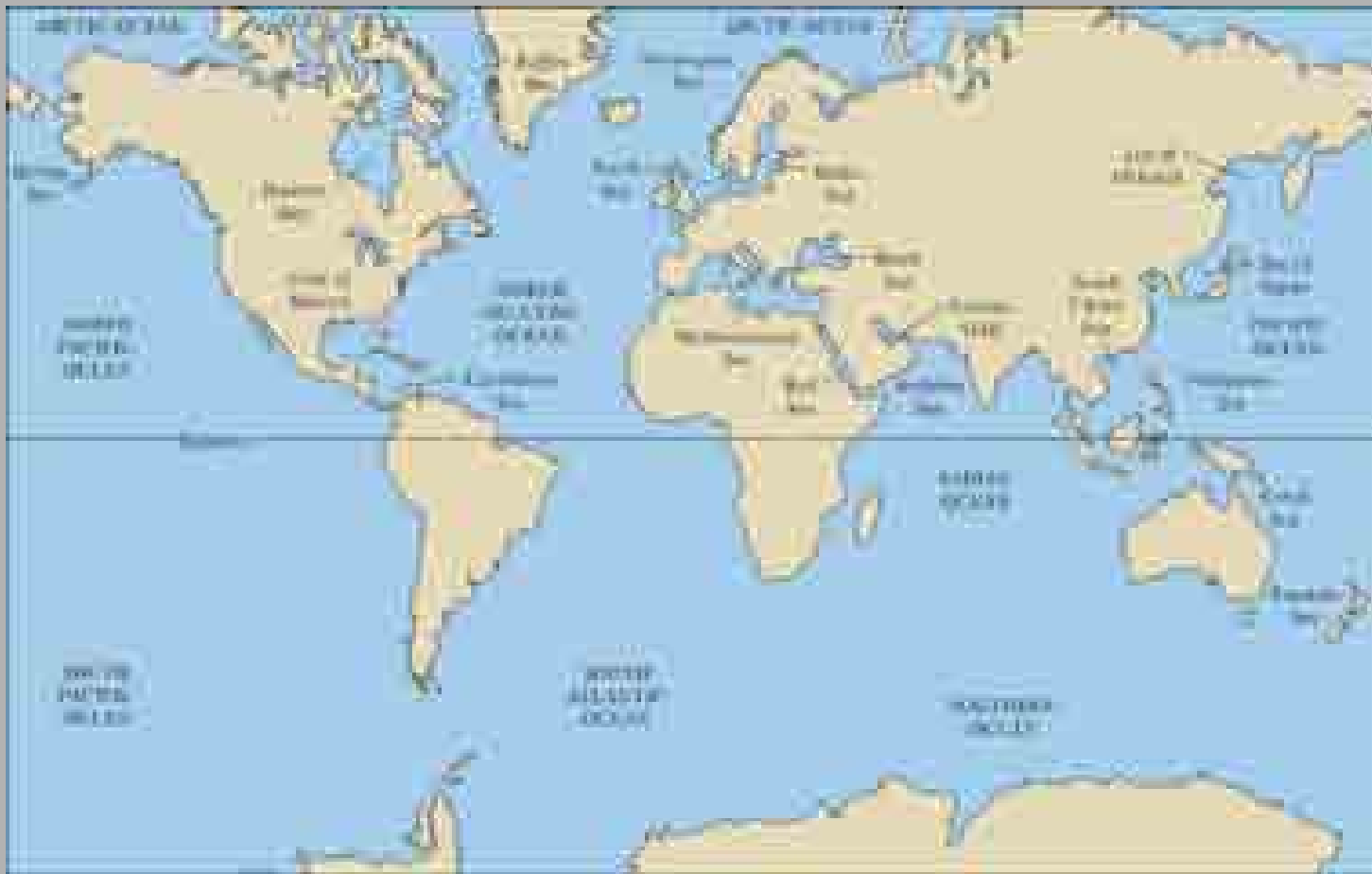
- The seafloor is the largest part of Earth's surface. **Many seafloor features and processes provide evidence of plate tectonics.** Seafloor sediments and rocks are a source of several important natural resources.
- The oceans are the largest reservoir of the hydrosphere. The transfer of energy from the oceans to the shoreline result in erosion and deposition.
- From a practical standpoint, it is important to understand shoreline processes because many major centers of commerce and much of Earth's population are concentrated in a narrow band at or near shorelines.

Coastal Zones

- Coastal zones are of considerable importance to both people and wildlife
- ~40% of the US population live in coastal region and this number is growing rapidly
- 30 of the 50 US states abut a major body of water
- Home to 45% of US threatened or endangered species, 30% of waterfowl
- Vancouver, Halifax and even Toronto all have significant coastal areas

Oceans & Shorelines

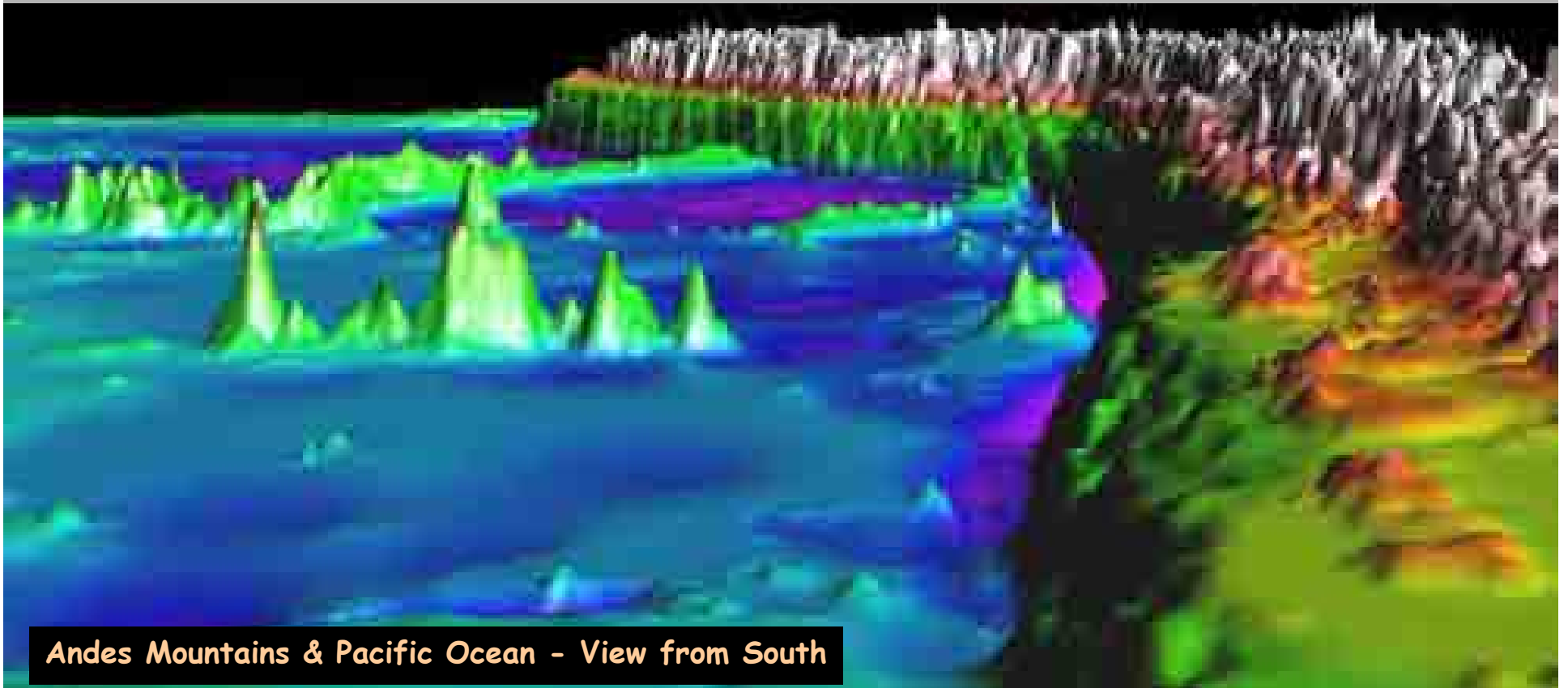
Most of Earth is covered by bodies of saltwater known as oceans. Ocean basins are not simply water covered land, but differ fundamentally from continents.



Marshak
(2002)

Oceans and shorelines

The ocean basins are not vast featureless plains, but have greater topographic relief than that of any continent.



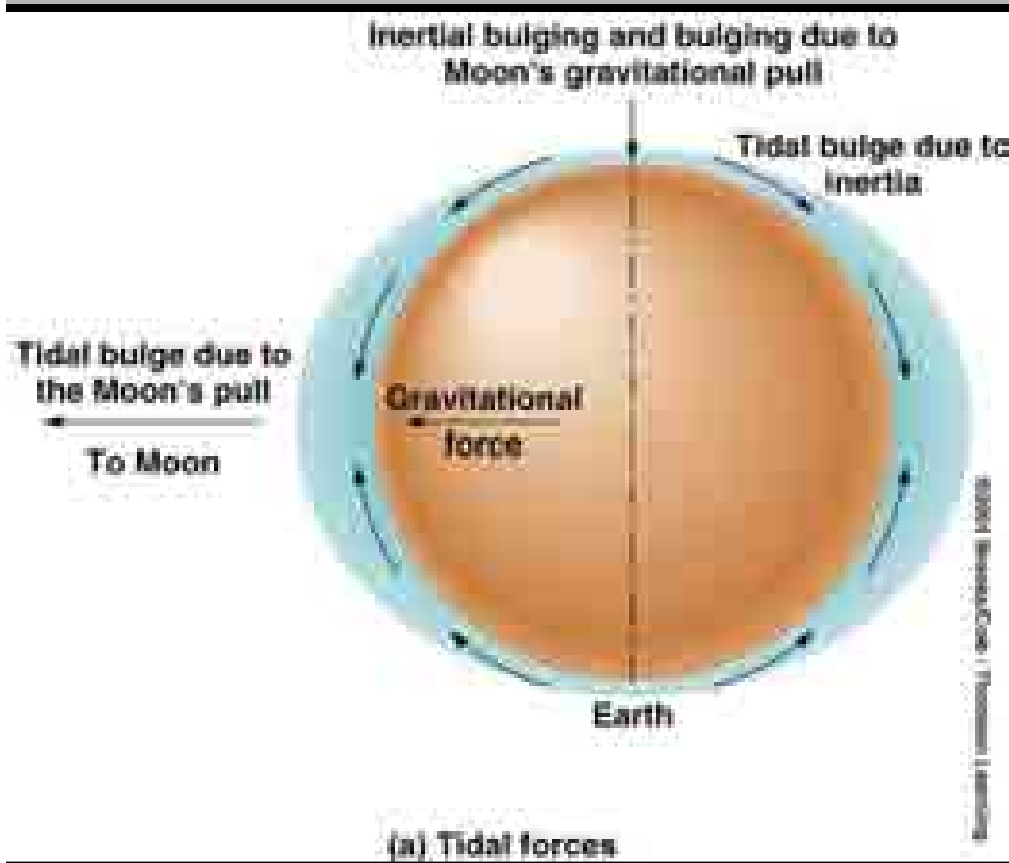
Andes Mountains & Pacific Ocean - View from South

Shorelines

- The shoreline is the boundary between ocean and land. It consists of the area between low tide and the highest level of land affected by storm waves.
- Shorelines are dynamic areas where energy is expended, erosion takes place, and sediment is transported and deposited.



Tides



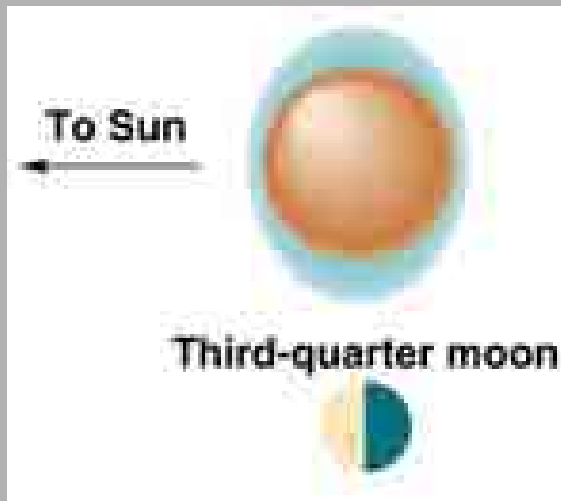
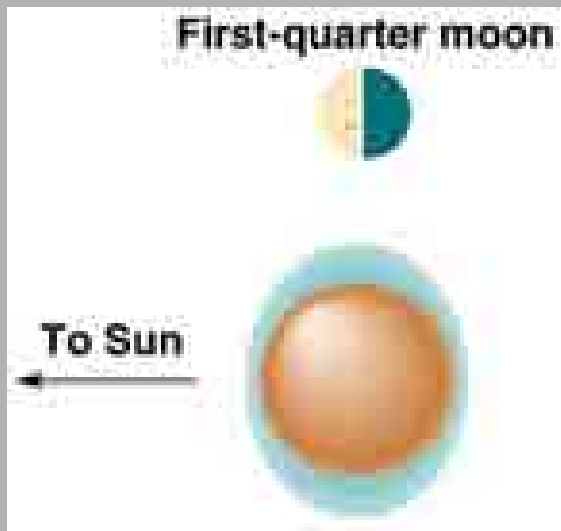
Gravitational attraction to the Moon and Earth's rotational inertia produce bulges on the ocean surface. Earth's rotation beneath these bulges causes a cyclic rise (flood tide) and fall (ebb tide) of sea level known as the tides. The Moon orbits Earth as Earth rotates, & so it takes 50 minutes longer each day for a given location to return to the high tide position beneath a tidal bulge. Therefore, high tide occurs 50 minutes later each day.

Tides

- In addition to the Moon, the Sun's gravitational attraction also effects tides in Earth's oceans. The Sun's effect, however, is less than half that of the Moon's.
- Due to the Moon's 28-day orbit of Earth, the Sun and Moon align every two weeks and their attractive forces act together to produce spring tides that are about 20% higher than average tides. This occurs in the "new" and "full" moon phases of the lunar cycle



Tides

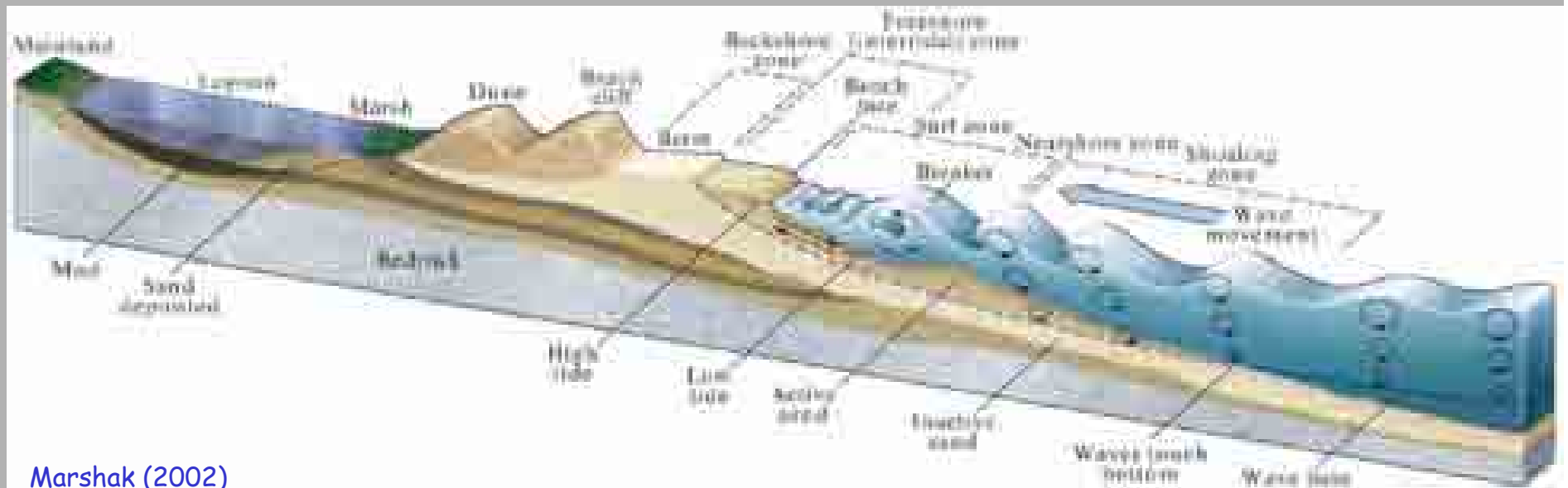


Also at two-week intervals the Sun and Moon are at right angles to each other such that the Sun's tide-generating force is canceled by some of that of the Moon's. This occurs in the first- and third-quarter phases of the lunar cycle. This orientation of Earth and the Sun produces neap tides which have high tides about 20% lower than normal.

Tides have a significant impact on shoreline dynamics because the area of wave attack constantly shifts onshore and offshore as tides rise and fall.

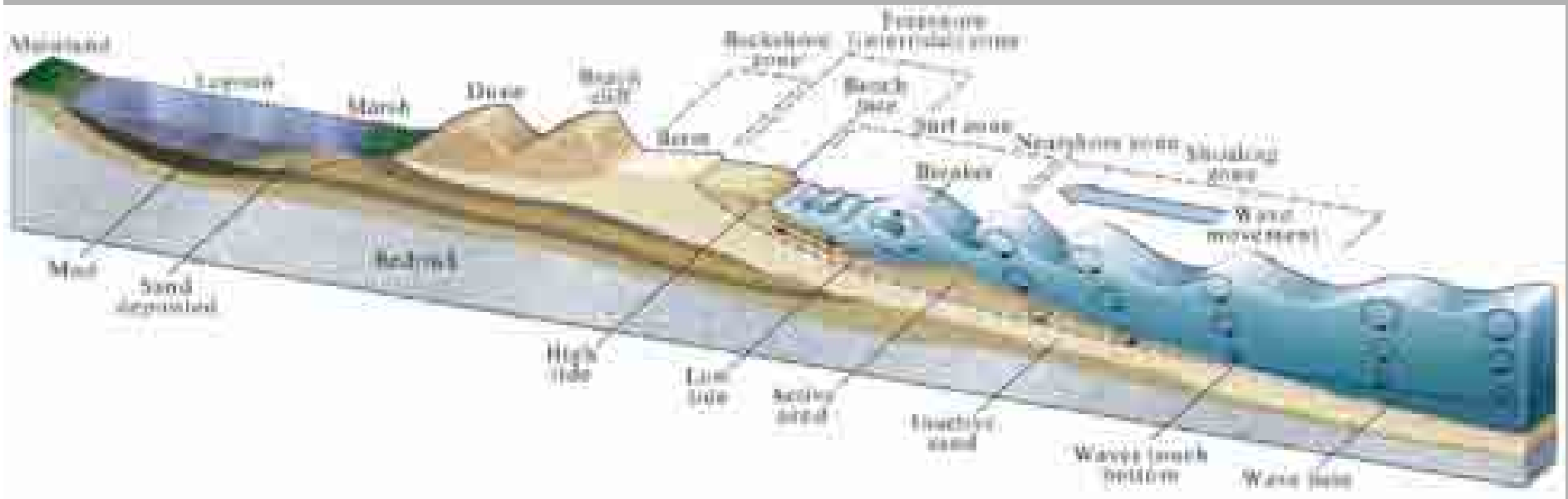
Coastlines – the fundamentals

- Shoreline – the boundary between sea and land that changes with the tides
- Coast – the area extending from the shoreline to the landward limit of features affected by marine processes
- Beach – gently sloping surface washed over by waves and covered by sediment



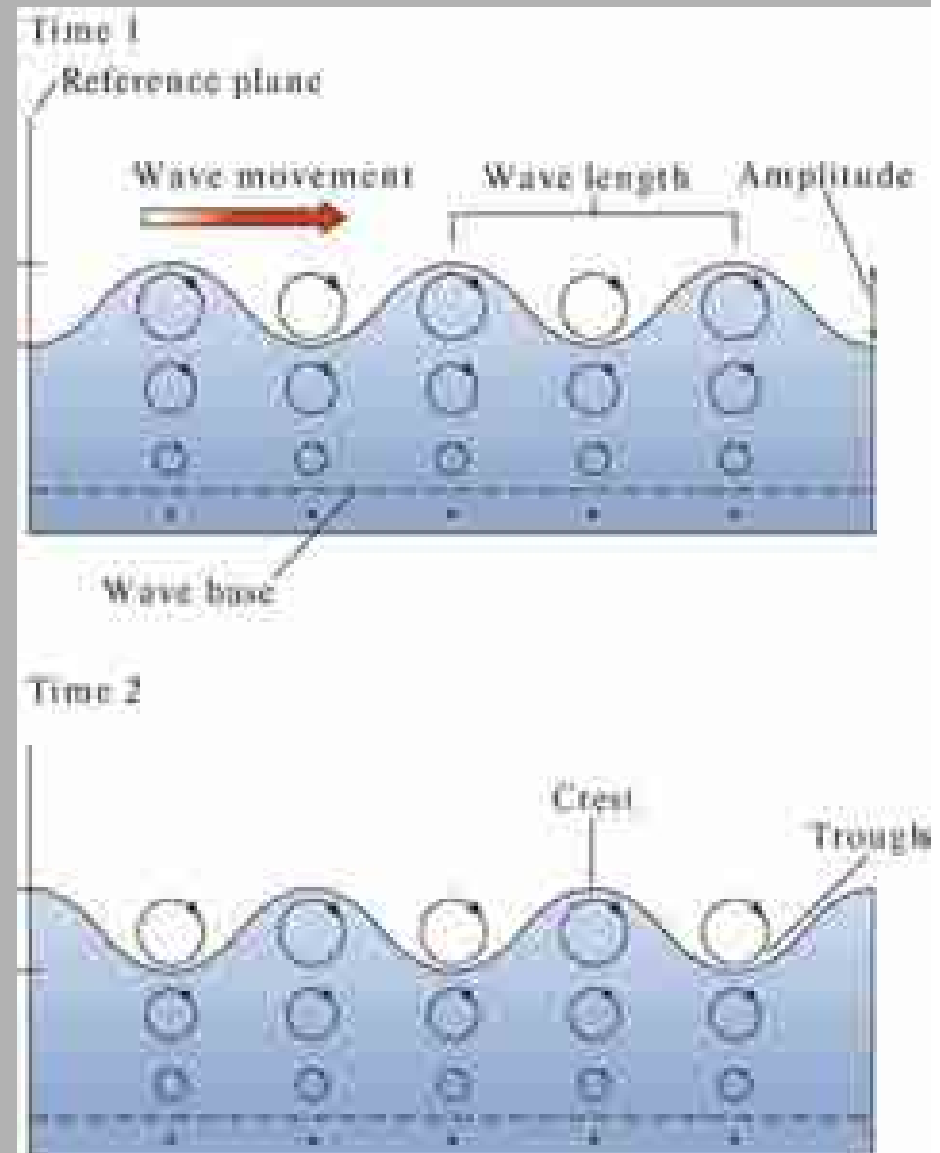
Coastlines – the fundamentals

- Waves – induced by the flow of wind across the water surface. The size of the waves is dependant upon
- Longshore current – because waves are rarely parallel to the shore these weak currents develop.
- Littoral drift – the transportation of sediment along the beach by longshore currents



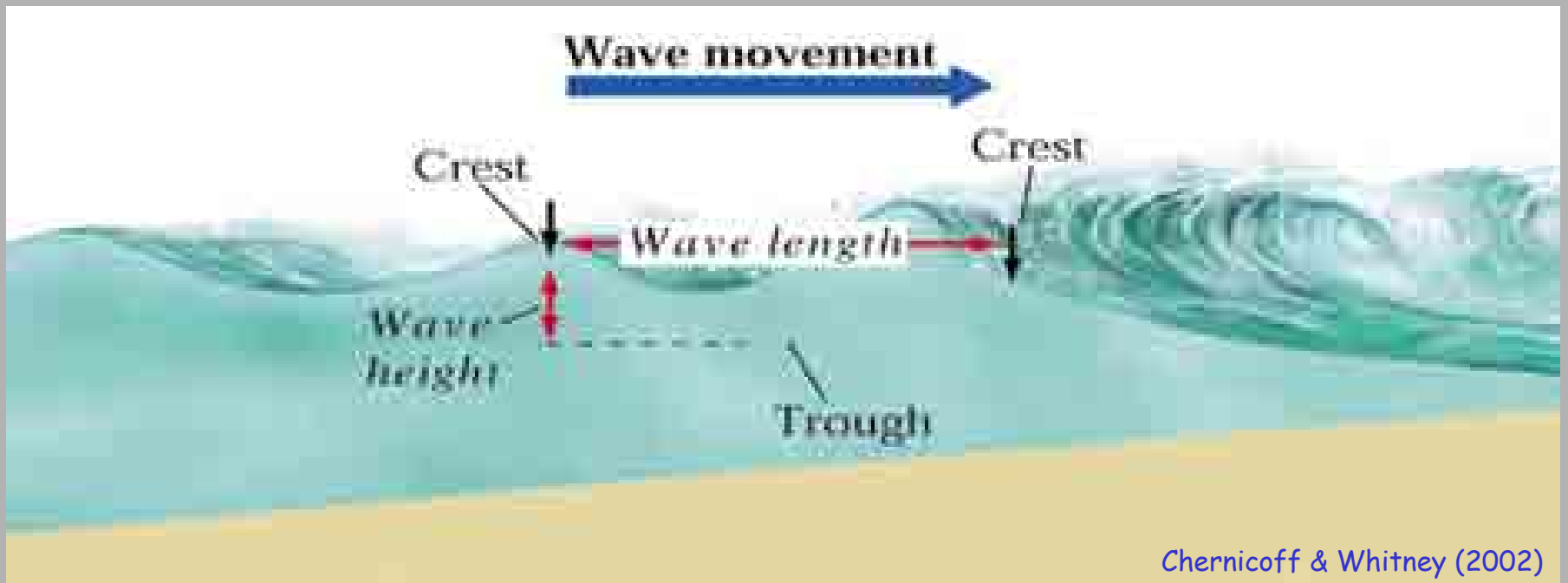
Waves

Waves are oscillations of a water surface and can erode, transport, and deposit sediment. The highest and lowest parts of a wave are the crest and trough.



Waves

Wavelength is the horizontal distance between wave crests and wave height is the vertical distance from crest to trough. Wave base is the depth to which a wave on the water's surface affects the underlying water mass. This depth is equal to one-half the wave length. At depths greater than wave base, the water and the seafloor are undisturbed.

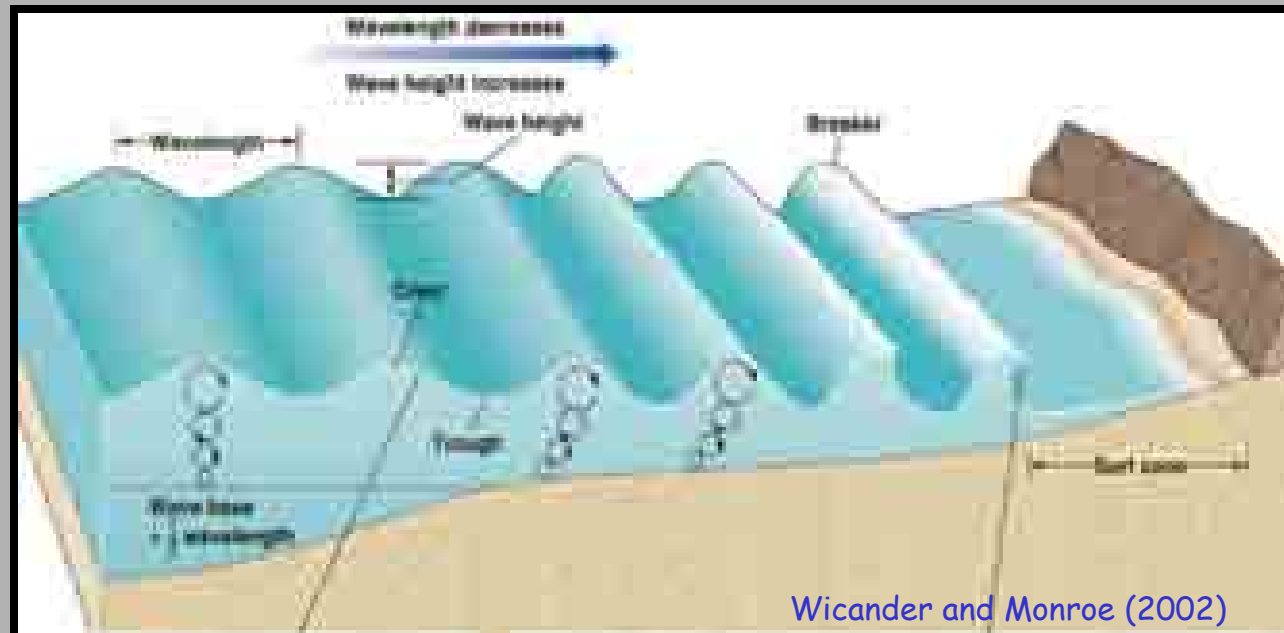


Wave Generation

- Although coastal and submarine landslides, seafloor faulting, and volcanic explosions cause waves, **wind-generated waves have greatest overall influence on shorelines.**
- Wind velocity and duration are important controls on the size of waves. Fetch, the distance the wind blows over open water, also affects the size of wind-generated waves.
- In areas where storm waves are generated, waves of different lengths, heights, and periods can merge to form rogue waves. **Rogue waves are excessively large waves that can range to three or four times larger than the average wind-generated wave.** Rogue waves with heights of 34m have been recorded during storms.

Waves & Breakers

Wind-generated waves moving across the deep ocean cause water particles to travel in orbital paths **with little net displacement** of the water. Broad, undulating deep-water waves become sharp-crested, higher, and more closely spaced as they move into shallow water (less than wave base) and begin to interact with the seafloor. Here the wave crest advances faster than the rest of the wave due to frictional interaction with the seafloor. As a result, the waves over-steepen and the crests plunge forward as **breakers**.



Waves and Breakers



Breakers are commonly several times higher than deep-water waves. Two types of breakers are recognized. Plunging breakers are produced in areas with steep offshore slopes. Spilling breakers build up slowly and the wave's crest spills down the front of the wave. They form in areas with gentle offshore slopes.



Nearshore Currents

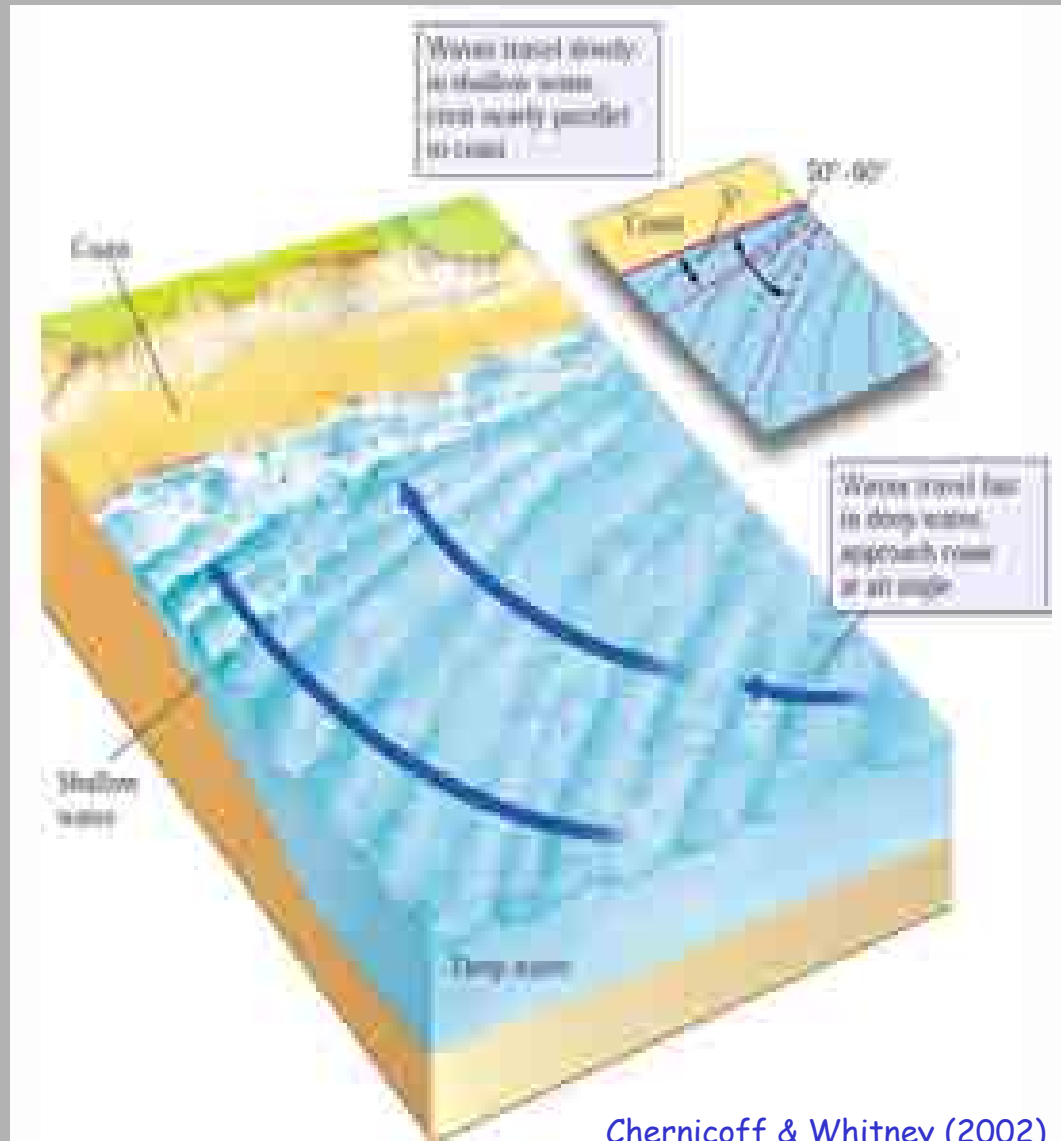
The nearshore zone is the coastal area reaching from the upper edge of the shoreline to the area where waves begin to break as they rush toward the shoreline. The nearshore zone includes both the breaker and surf zones where water carried to the shoreline by waves returns seaward as backwash.



Two types of currents are generated in the nearshore zone by incoming waves.

Wave refraction.

Waves approach the shoreline at various angles, but rarely do their crests parallel the shore. Therefore, various parts of a wave enter shallow water and begin to slow while other parts still in deeper water have not yet been slowed by friction with the seafloor. In this way, wave refraction causes waves to bend more nearly parallel to the shoreline.



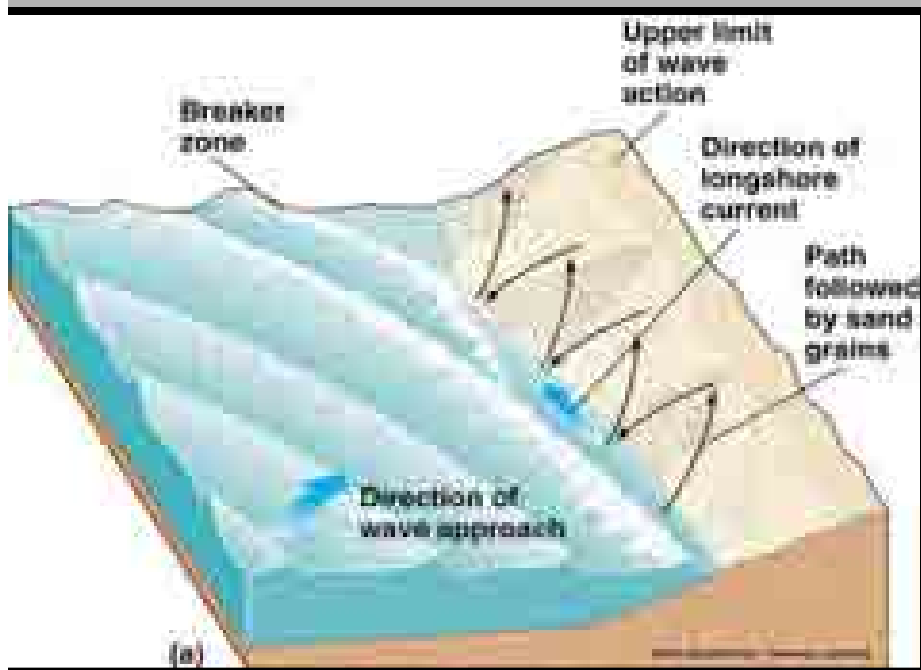
Chernicoff & Whitney (2002)

Wave refraction



Wicander and Monroe (2002)

Nearshore Currents



Wicander and Monroe (2002)

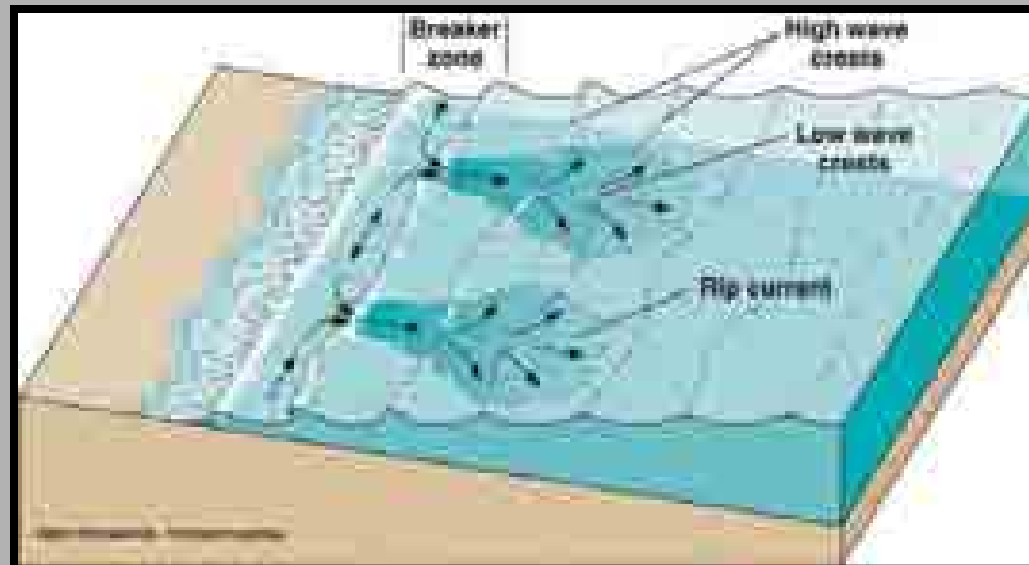
In this way, wave refraction causes waves to bend more nearly parallel to the shoreline. Even though refraction bends waves as they approach the shoreline, they still strike it at an angle. **This produces a component of flow parallel to the beach and known as longshore current. This current moves and deposits large volumes of sediment in the nearshore zone.**

Rates of littoral drift

Location	Drift rate yd ³ /yr
Newport Beach	300,000
Santa Barbara	250,000
Santa Monica	160,000
Fire Island inlet NY	350,000
Rockaway Beach NY	260,000
Palm Beach, Florida	130,000
Great Lakes	43,000

Nearshore Currents

- Rip currents are narrow surface currents that flow seaward from the shoreline out through the breaker zone. They are an important mechanism for transferring back out to sea the water carried to the nearshore by waves.
- Rip currents flow at several km/hr and can be a hazard for swimmers. Swim parallel to the shoreline to escape a rip current.



Wicander and Monroe (2002)

Rip current



Wicander and Monroe (2002)

Shorelines - Beaches

- Beaches are unconsolidated deposits of sediment that extend landward from low tide to a line of sand dunes, cliffs, or the beginning of permanent vegetation.



northern California

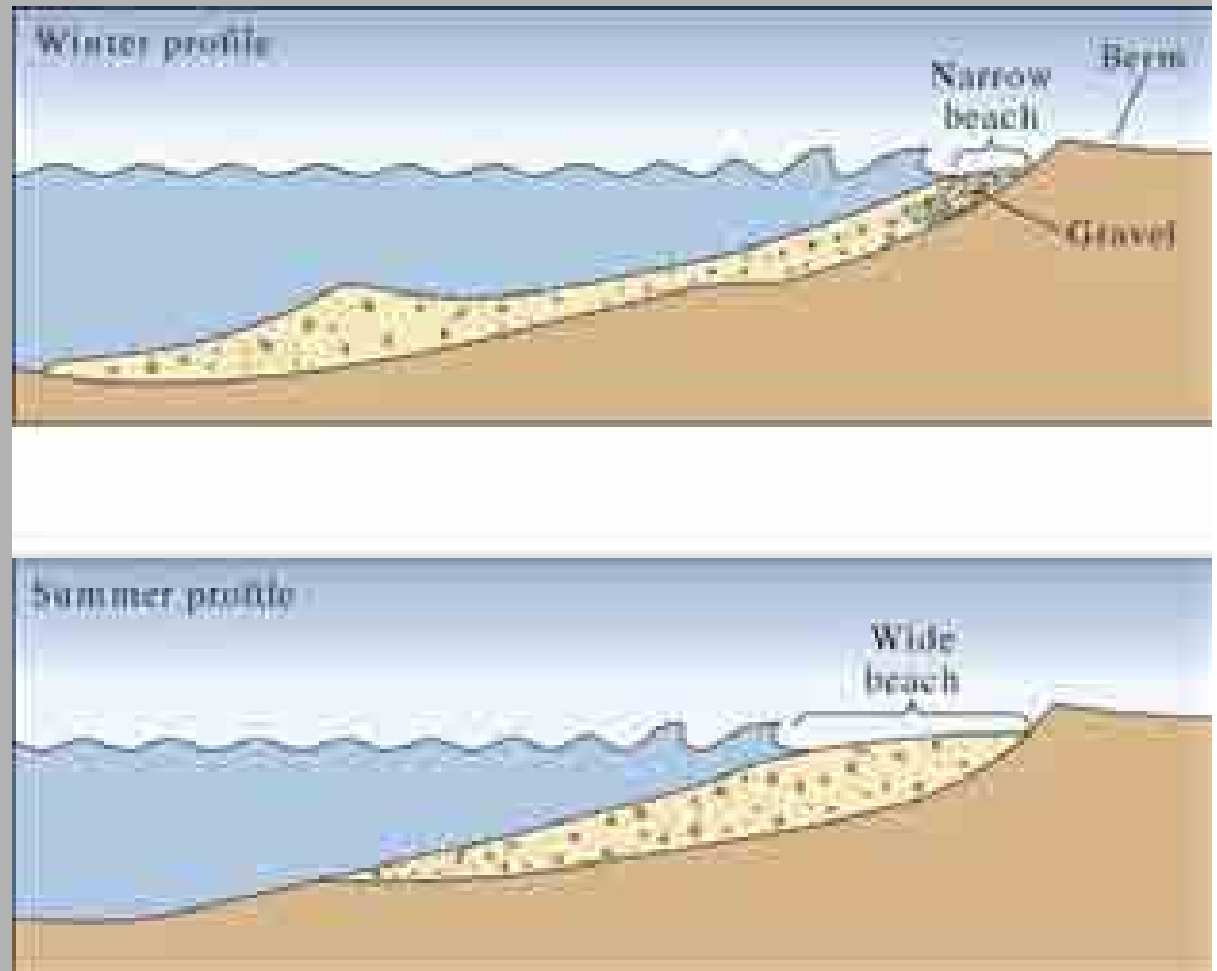
Shoreline configuration and wave intensity control whether *pocket beaches* (left), discontinuous beaches in protected areas, or long continuous beaches form.

Beaches

- Some beach sediment is derived by shoreline erosion in other areas, but most is delivered to the seas by rivers and streams.
- Longshore drift, transport of sediment by longshore current, redistributes these sediments along beaches.
- Seasonal changes in storm wave intensity affect beach profiles

Beach erosion

However, all beach types are affected by seasonal variations. High energy winter storms tend to result in smaller winter beaches.



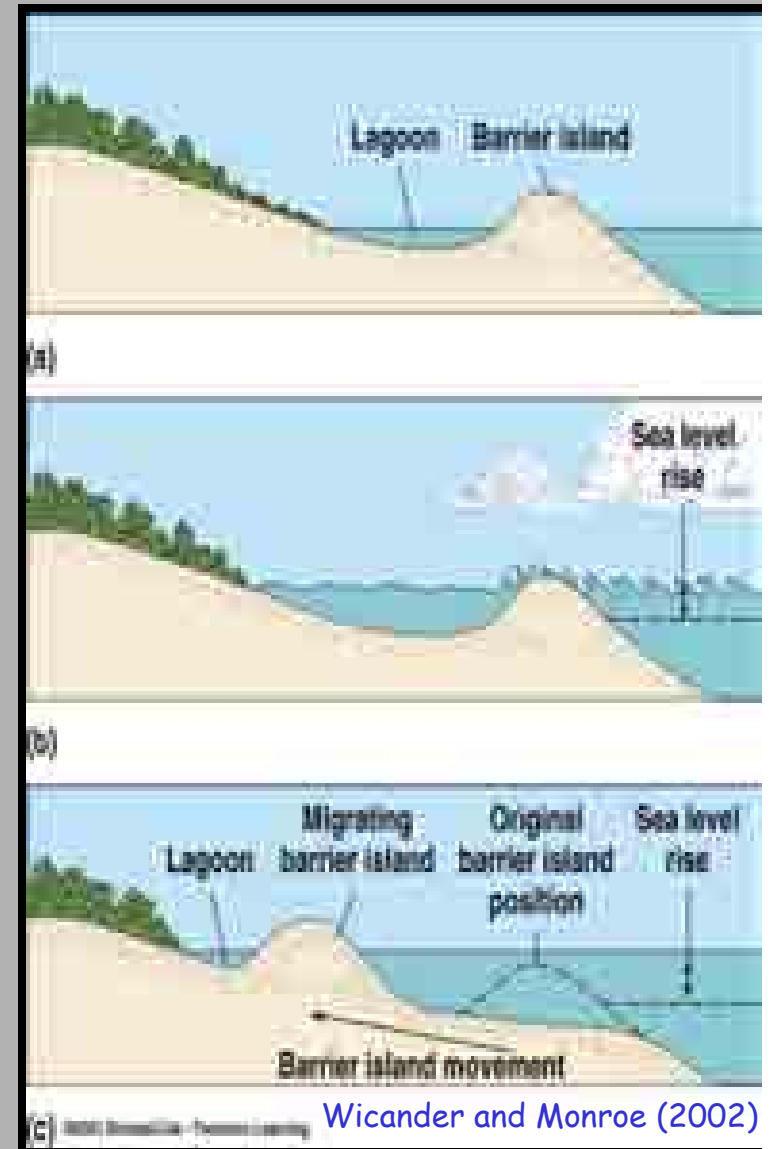
Beaches and erosion

- **Basically four types of beach**
 - Coastal-plain or mainland beaches
 - Pocket beaches
 - Barrier islands
 - Sand spit beaches



Barrier Islands

Barrier islands are long, narrow, emergent strips of sand separated from the mainland by lagoons. Common along the southeastern coast of the U.S. and the Texas Gulf Coast, barrier islands include beaches, wind-laid sand dunes, and marshes. Formed where beach ridges subside or spits become detached from land, barrier islands shift landward over time fast enough to cause problems for island property owners.

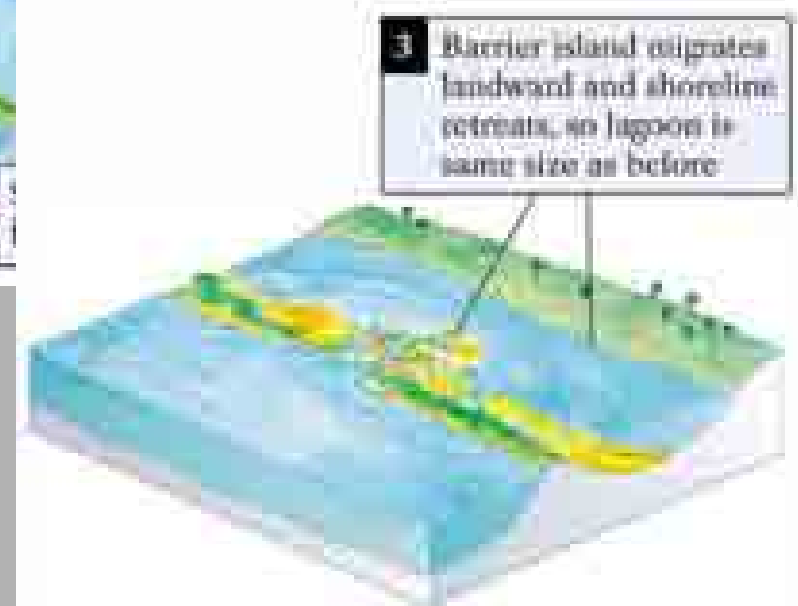
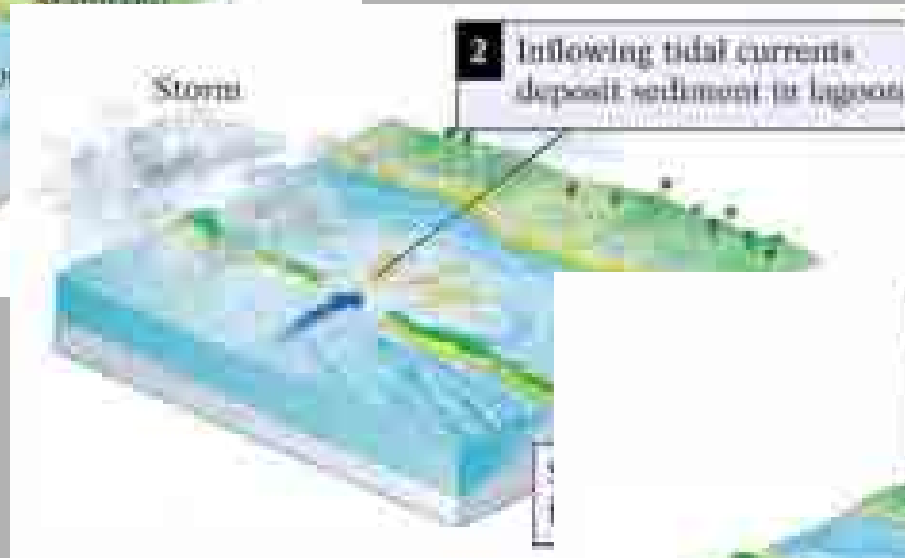
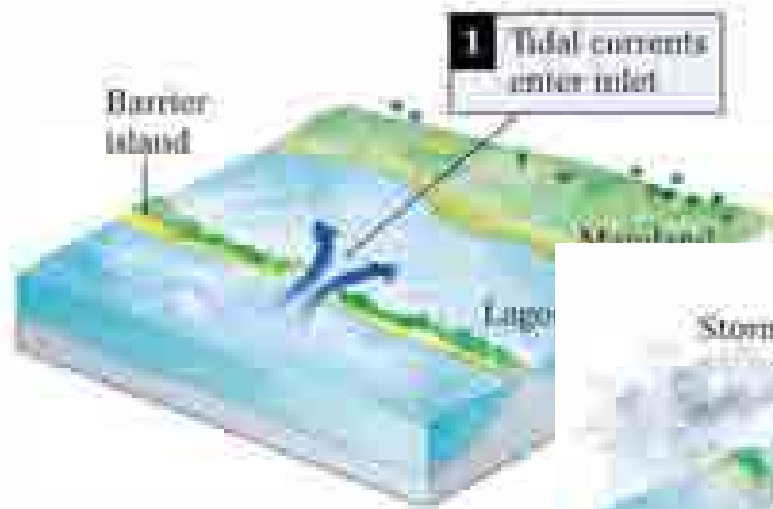


Barrier islands & spits

- These comprise the most extensive and tenuous beach system in the US, running from Long Island through to Texas
- Barrier beaches are transient features, formed, destroyed and reshaped by wave action. Typical Atlantic coast migration rates are 2m shoreward per year

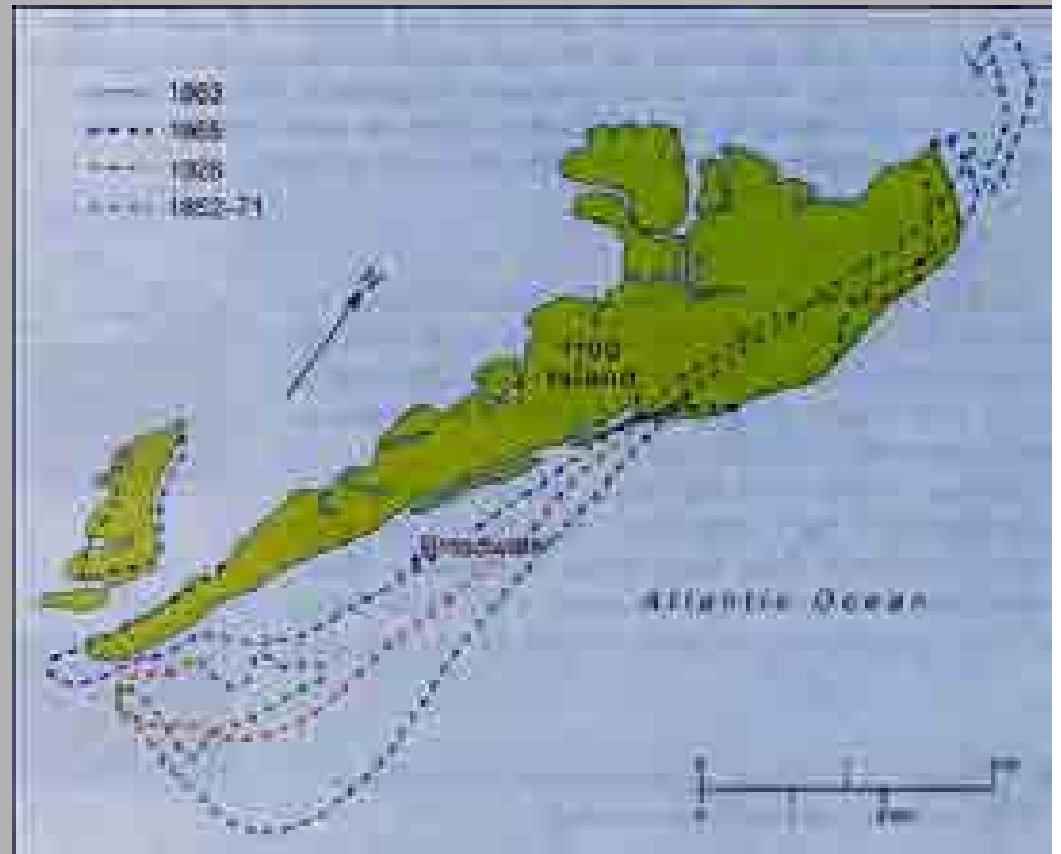


Barrier island migration



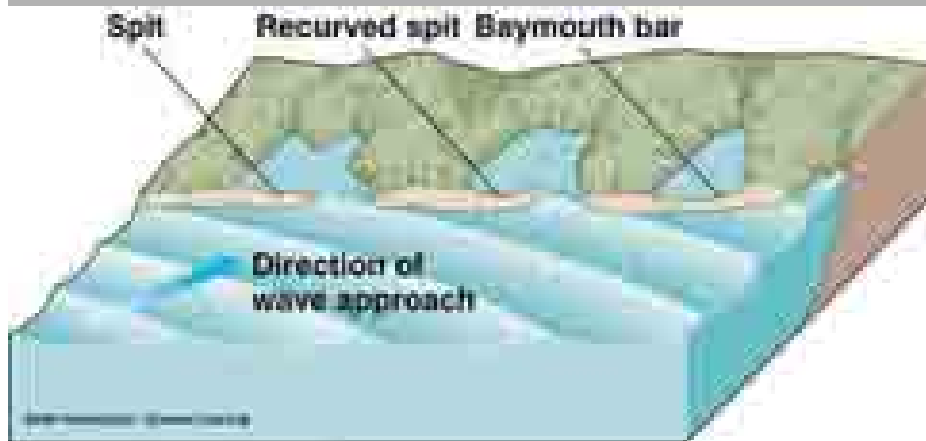
Hog Island, Virginia

- In 1933 a hurricane innundated the island killing the pine forest
- The village of Broadwater with 50 houses and a school is now 500m offshore



Pipkin and Trent (1997)

Spits and bars



Spits are finger-like lateral projections of beaches into bays. Baymouth bars are spits that have grown to close off a bay from the open sea.



Russian River, Calif.

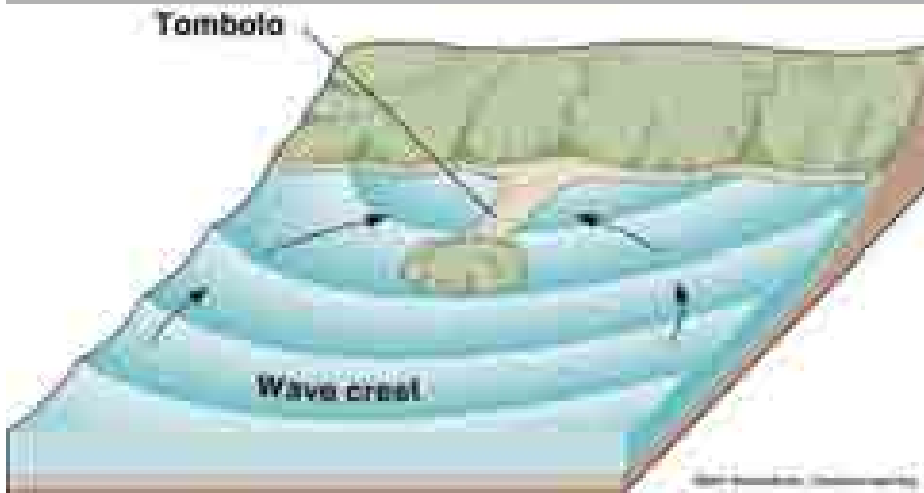


Wicander and Monroe (2002)

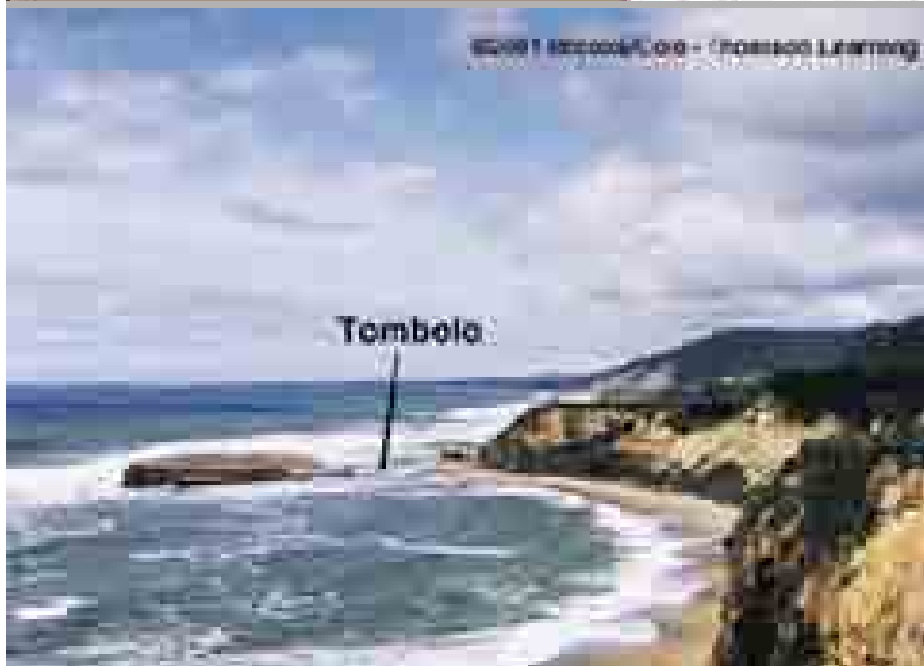
Spits and bars



Spits, Bars and Tombolos



- Tombolos are a relatively rare type of spit formed where wave refraction around an island combines with longshore drift to build a deposit of sediment that connects the island to the mainland
- Spits and baymouth bars can become problems where bays must be kept open for recreational and commercial use. Dredging or protective structures are often required.



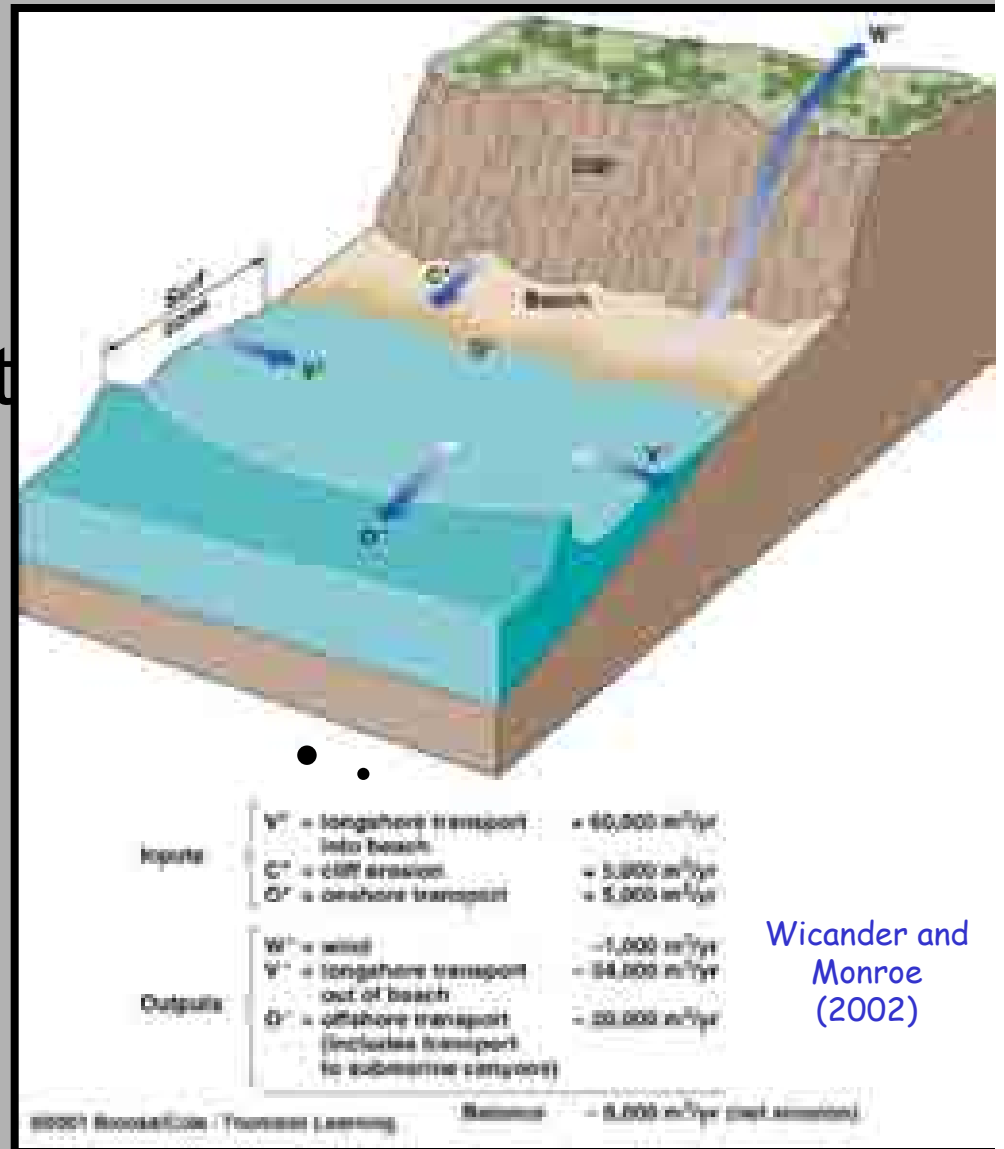
Tombola



Wicander and Monroe (2002)

Nearshore Sediment Budget

The nearshore sediment budget concerns the gains and losses of sediment and determines for example whether beaches are eroding or accreting.

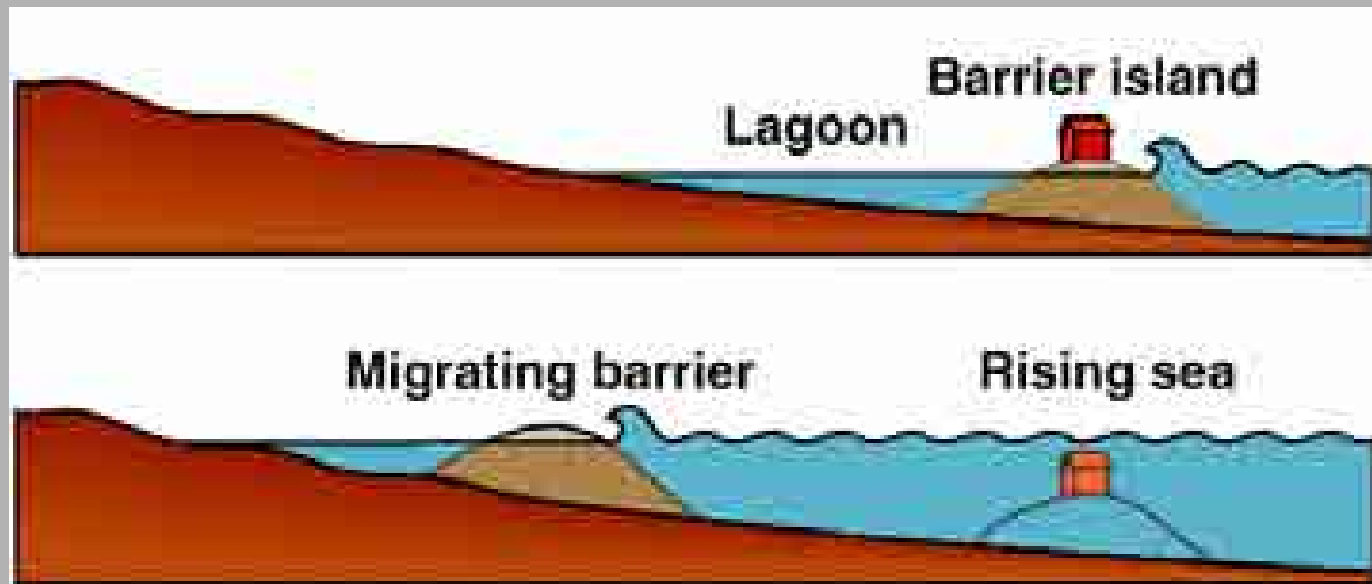


Erosion the causes – global

- Drought – drought results in little surface run off and consequently little sand is supplied to beaches.
- The practice of damming rivers for flood control or irrigation mimics this process. 80% of Southern California's largest watershed (Santa Ana River) is behind a dam, beaches downstream are eroding. Similarly urbanisation seals away sediment that might otherwise be eroded into local rivers

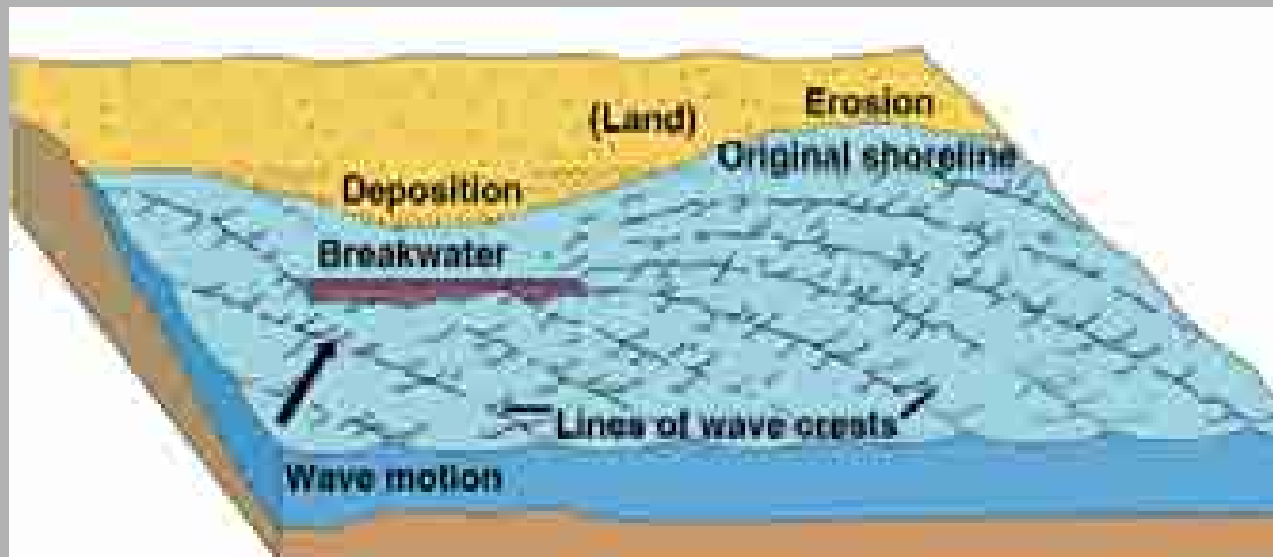
The causes – global scale

- Rising sea level – on a longer term global sea level changes related to glaciation have significantly modified coastlines. On a shorter time scale it is suggested that global warming will result in a 1-3m sea level rise.
- The effect of this will depend on the nature of the coastline and whether or not the coastline itself is being uplifted



The causes – local scale

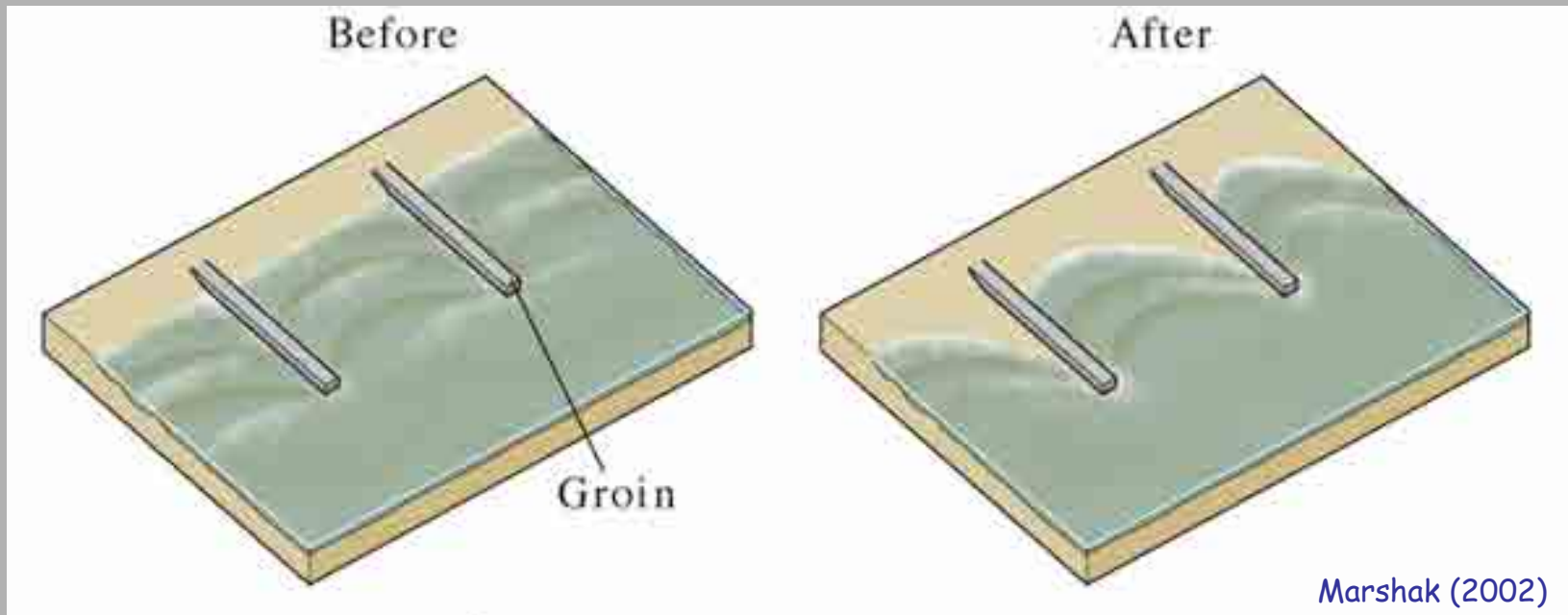
- When high frequency waves collapse they form plunging breakers which direct most of the force downwards, tending to remove the sand
- The majority of long-term beach erosion is aggravated by human activity.



Montgomery (2000)

The causes – local scale

- In general terms any plan designed to protect an area of coast from erosion will negatively impact on adjacent areas
- On a very small scale this is illustrated by the construction of groins on beaches.



Impact of jetties

On a larger scale the construction of jetties between Fenwick and Assateague islands in order to keep the channel open resulted the displacement of Assateague island 500m shoreward due to sand starvation

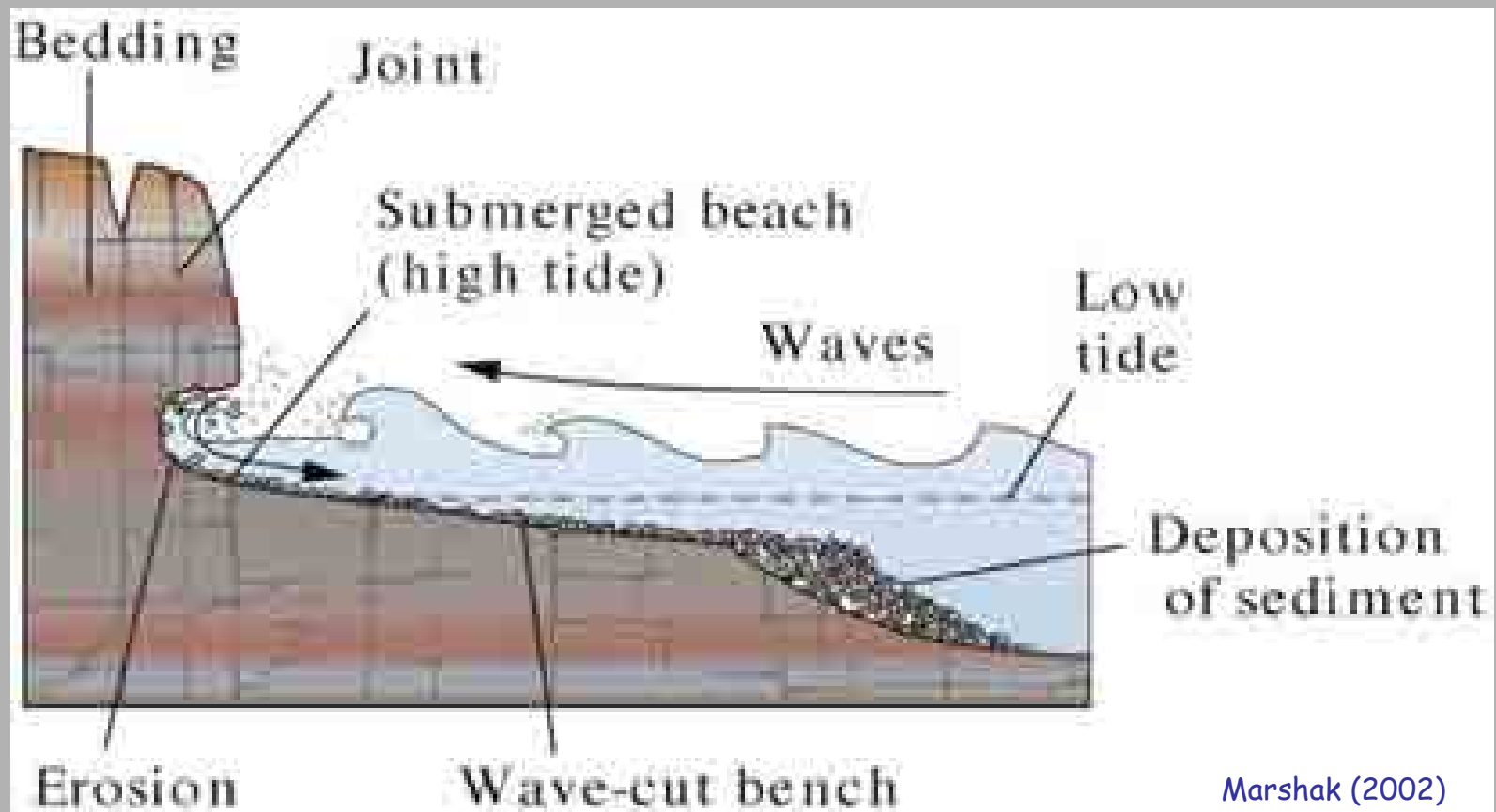


How Are Shorelines Eroded?

- On shorelines where sediment losses exceed sediment gains, erosion dominates, beaches are poorly developed and sea cliffs are common. Several processes derived from the pounding action of storm waves erode shorelines.
- Corrosion involves the wearing away of rocks by the chemical action of seawater.
- Waves exert great force on shorelines by direct impact. This hydraulic action is especially effective at eroding sea cliffs of sediment or fractured rock.
- Abrasion involves the grinding action of gravel and sand carried by waves.
- Over time, shoreline processes tend to straighten irregular shorelines by eroding headlands and infilling bays.

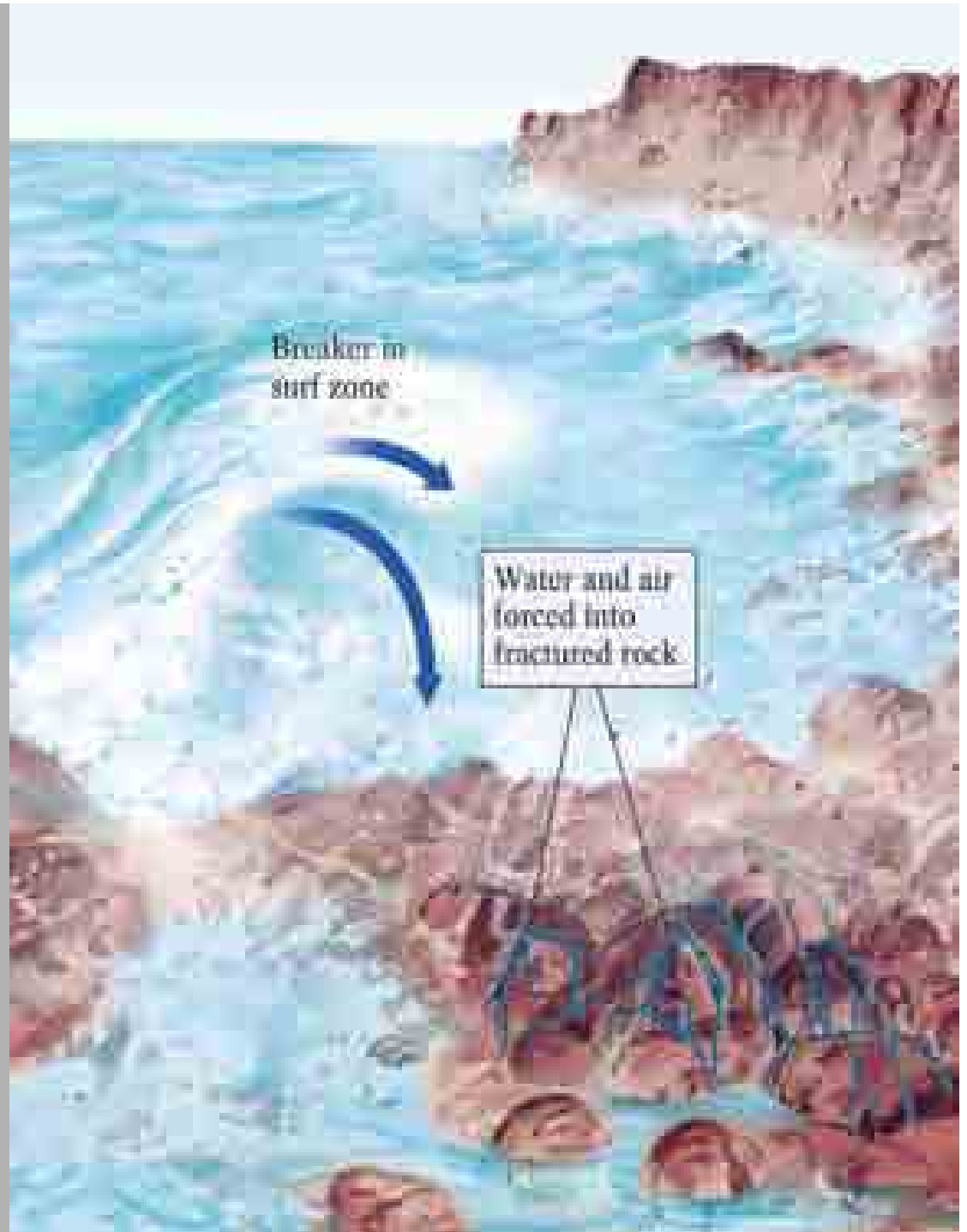
Sea cliffs

As with beaches sea cliffs are subjected to erosion by wave action at the base, but also by mass-wasting on the face and top.



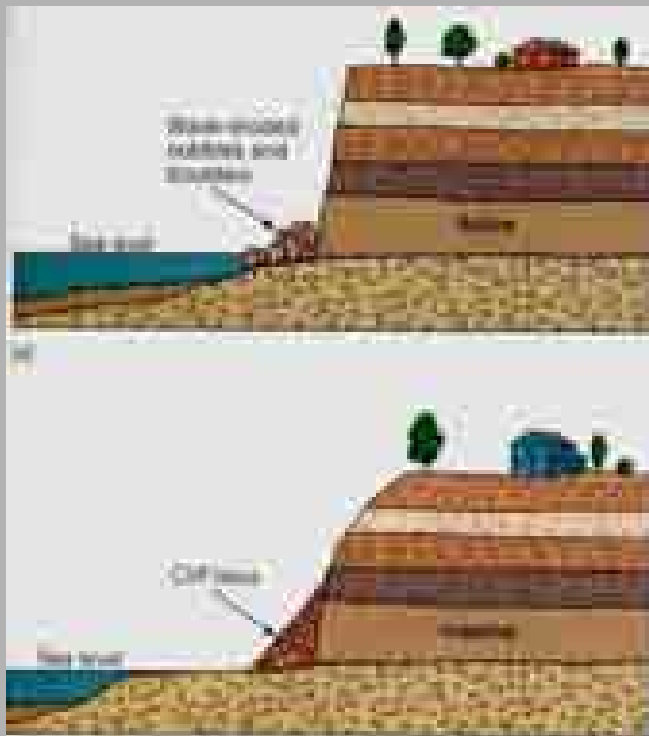
Sea cliffs

Erosion along the base of the cliff occurs as a result of either the direct pounding of the waves or by the grinding effect of sand and pebbles moved by the waves.



Sea cliffs

- Active sea cliffs are dominated by wave action resulting in steep cliffs with little talus at the base
- Inactive sea cliffs are dominated by mass wasting processes, have gentler slopes and larger talus slopes

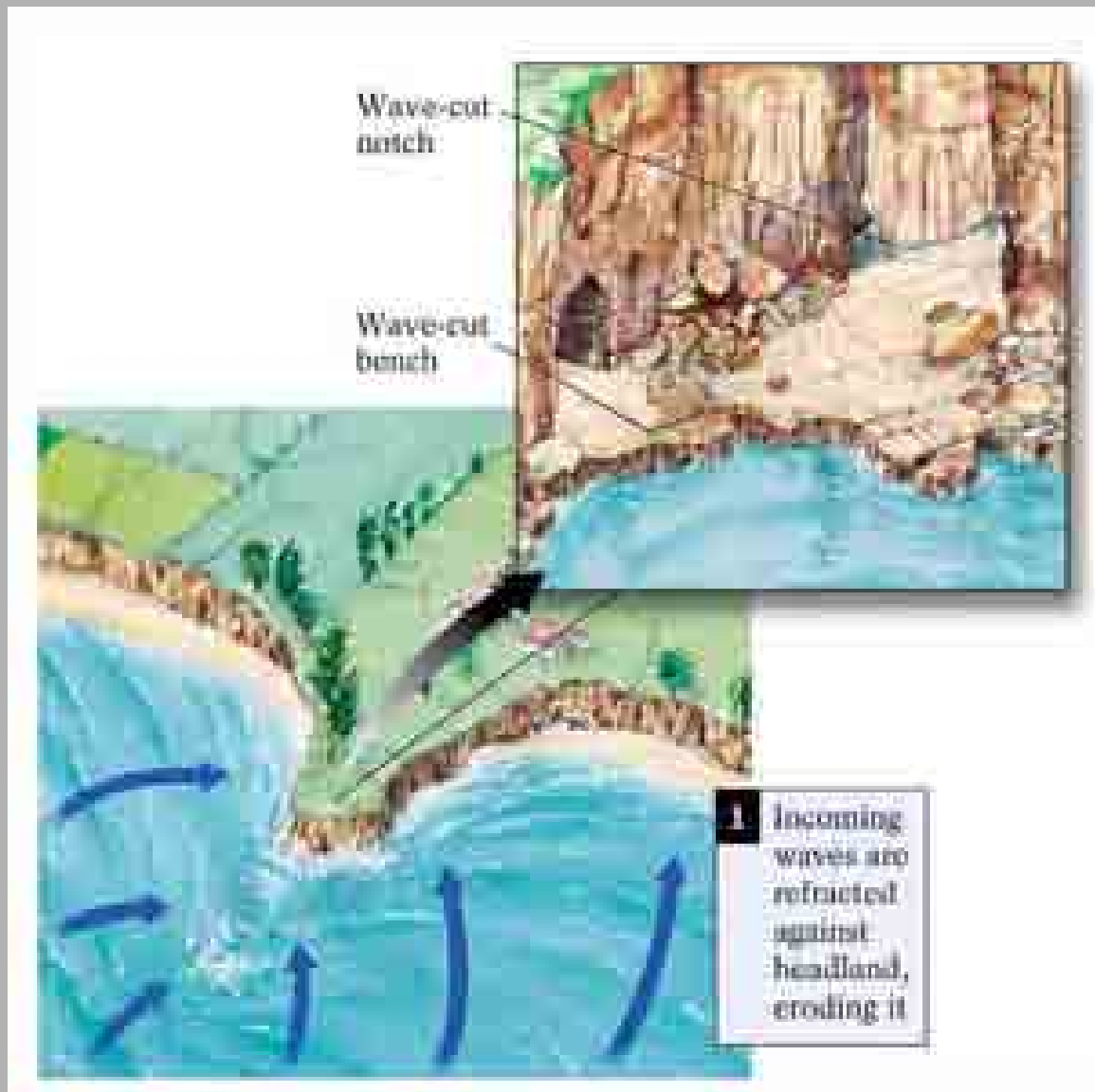


Pipkin and Trent (1997)

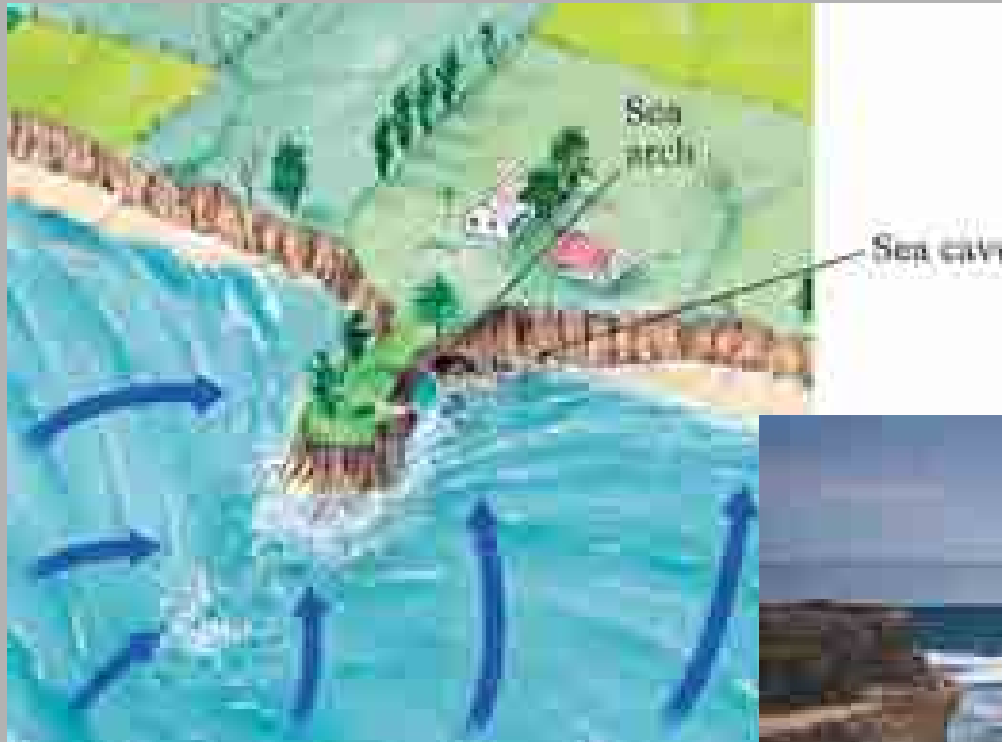


Marshak (2002)

Erosional coastal landforms.



Erosional coastal landforms

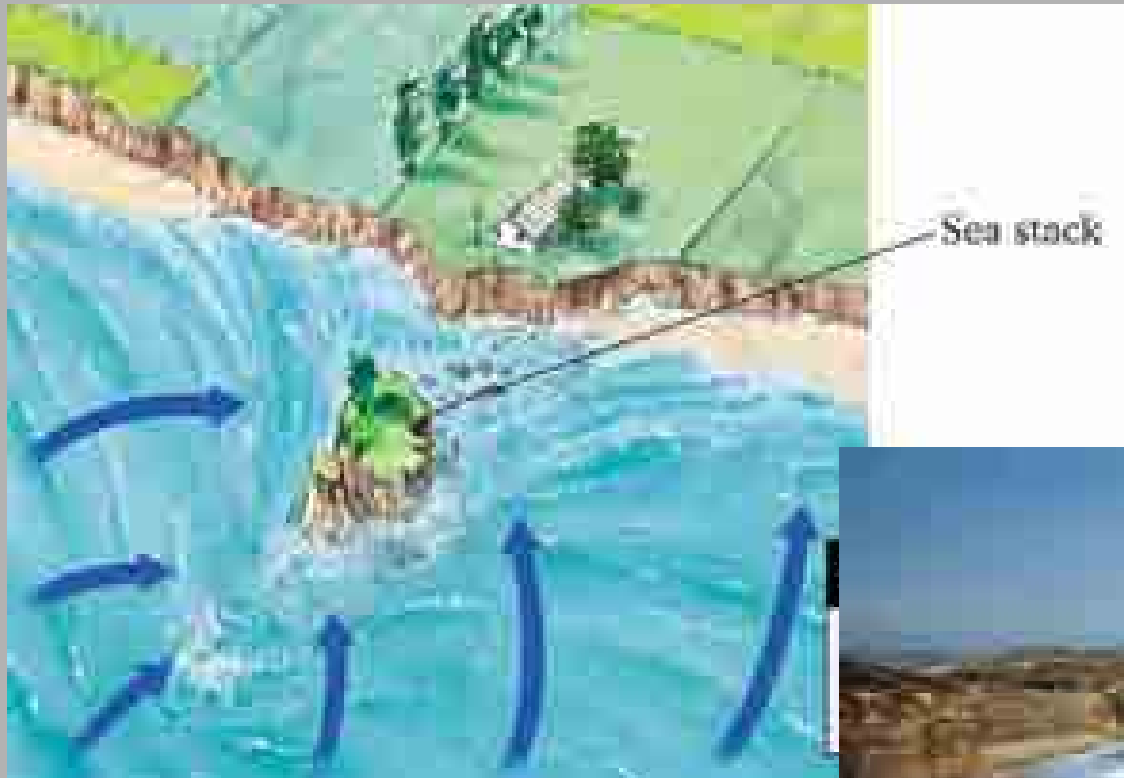


Chernicoff & Whitney (2002)



Marshak (2002)

Erosional coastal landforms

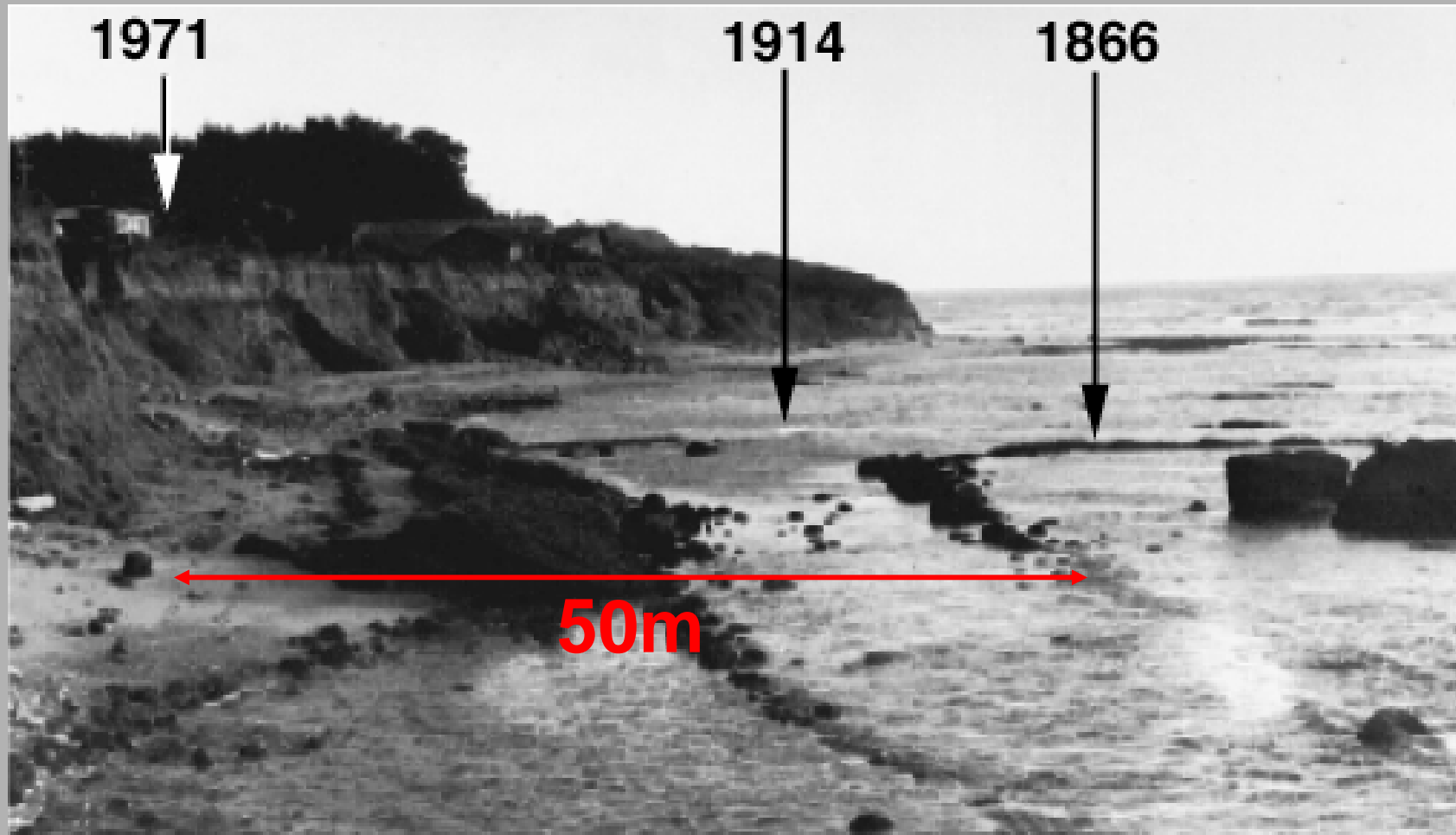


Chernicoff & Whitney (2002)



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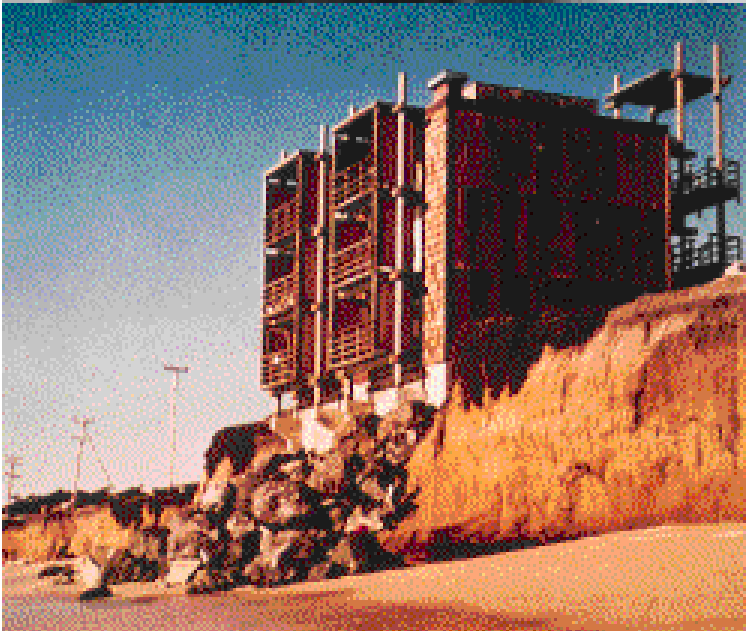
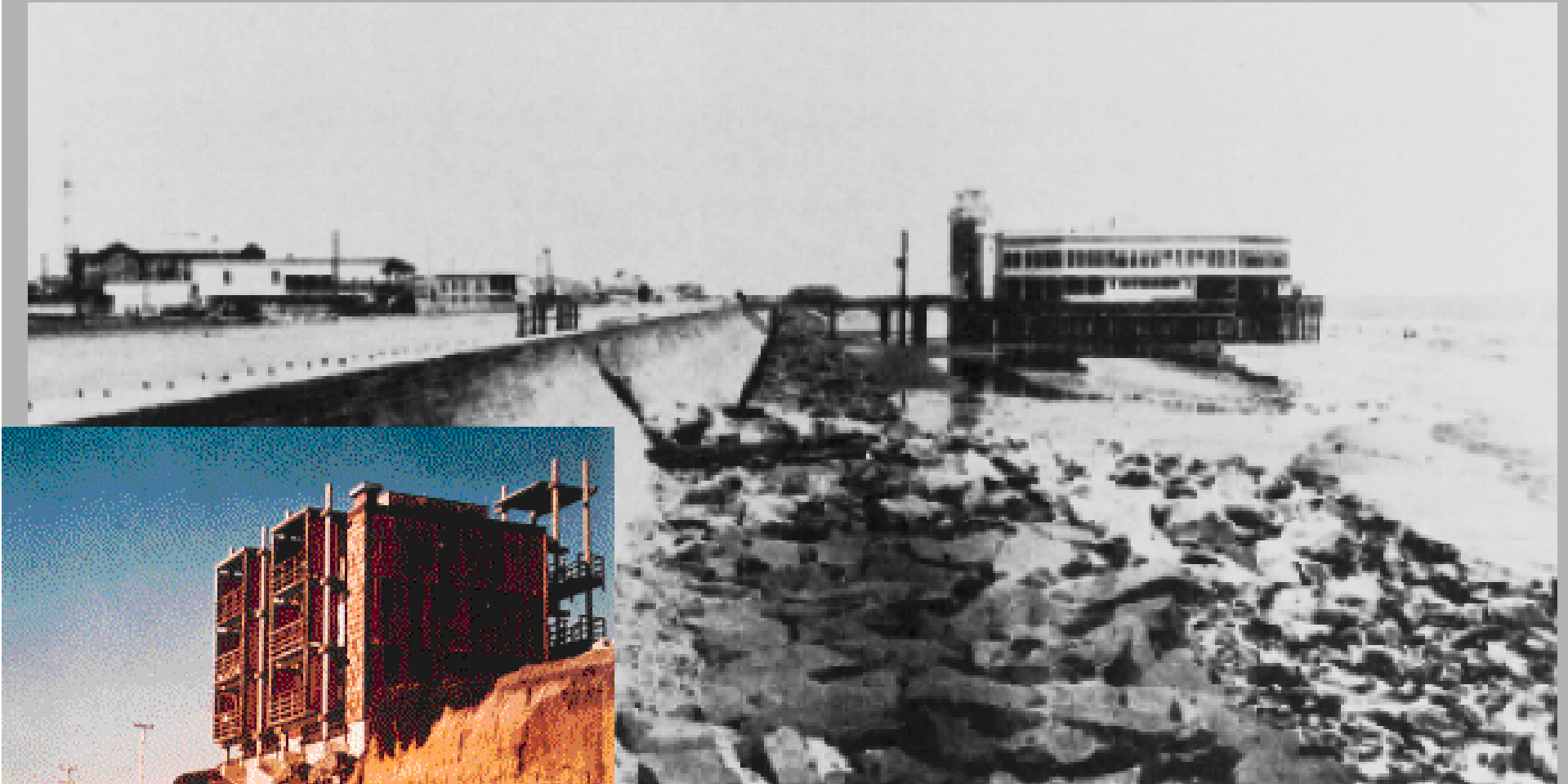
Moss beach cliffs



Mitigation of beach erosion

- All mitigation measures we can undertake are at best temporary and can do little against rising sea levels or large storms.
- Concrete seawalls – these are built parallel to the beach landward of the shoreline to protect the land behind the beach. They tend to reflect waves downward where it removes the sand of the beach. Wave erosion will also occur on the ends of the walls requiring their extension

Galveston sea wall - no beach!

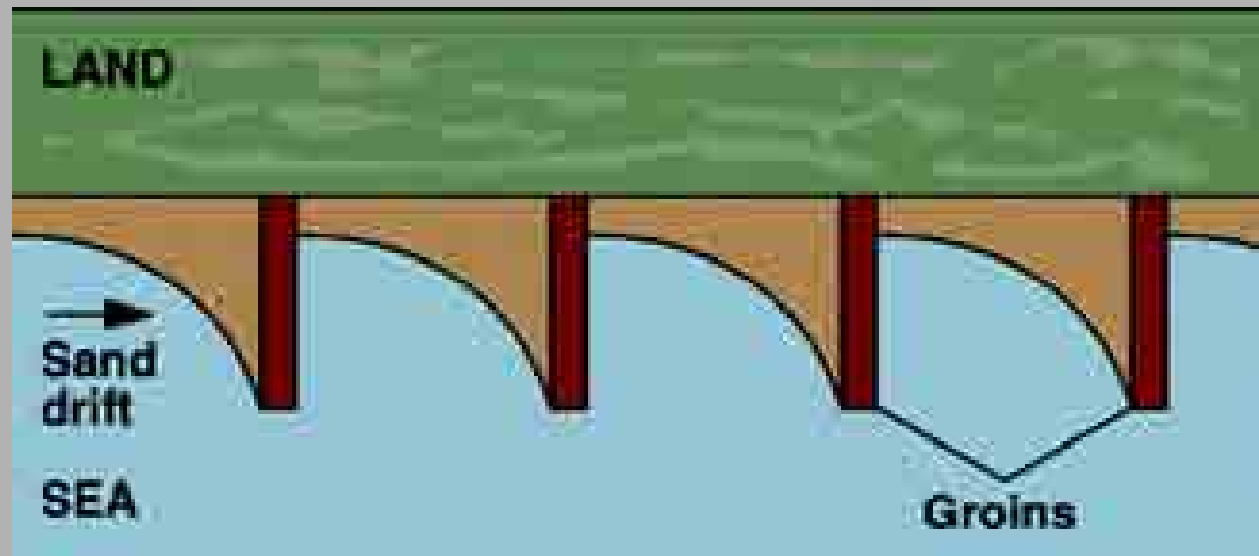


Montgomery (2000)

Montgomery (2000)

Mitigation of beach erosion

Groins – as discussed above groins trap sand on the upcurrent side but starve the downcurrent side. They have only a limited life as eventually the sand will build up to the point where it flows around the groin. Modern groins are often permeable to allow some sand to flow through



Plummer et al. (2001)

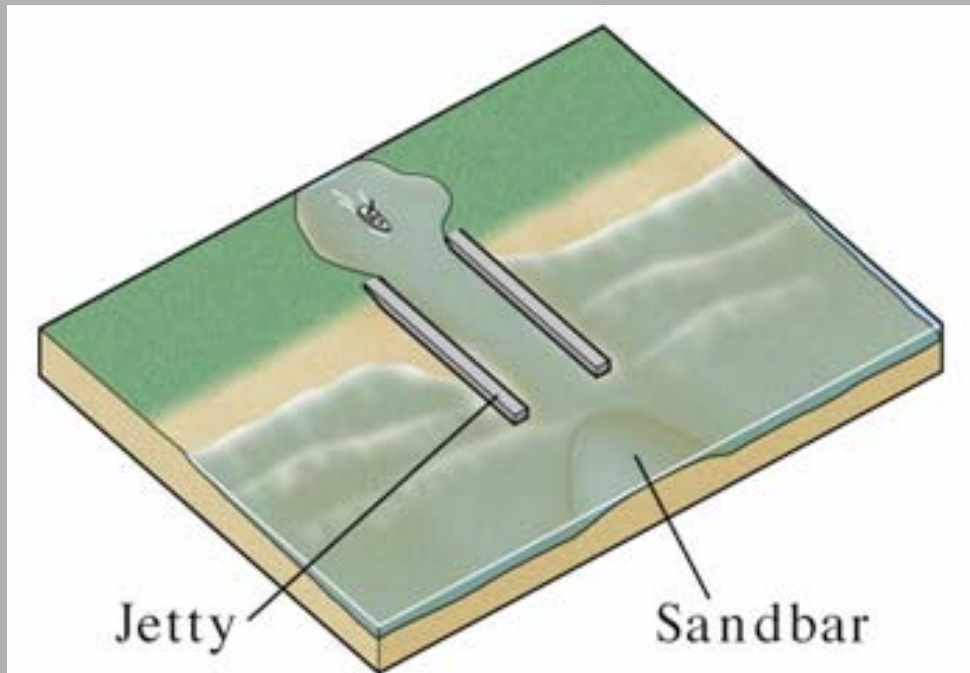
Groins



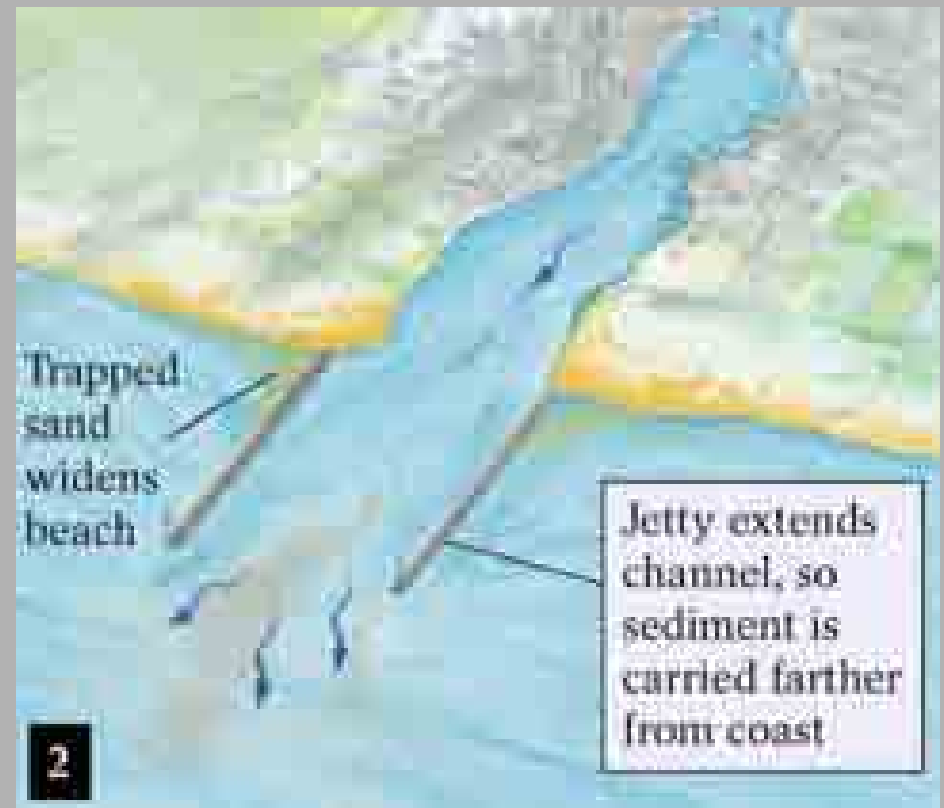
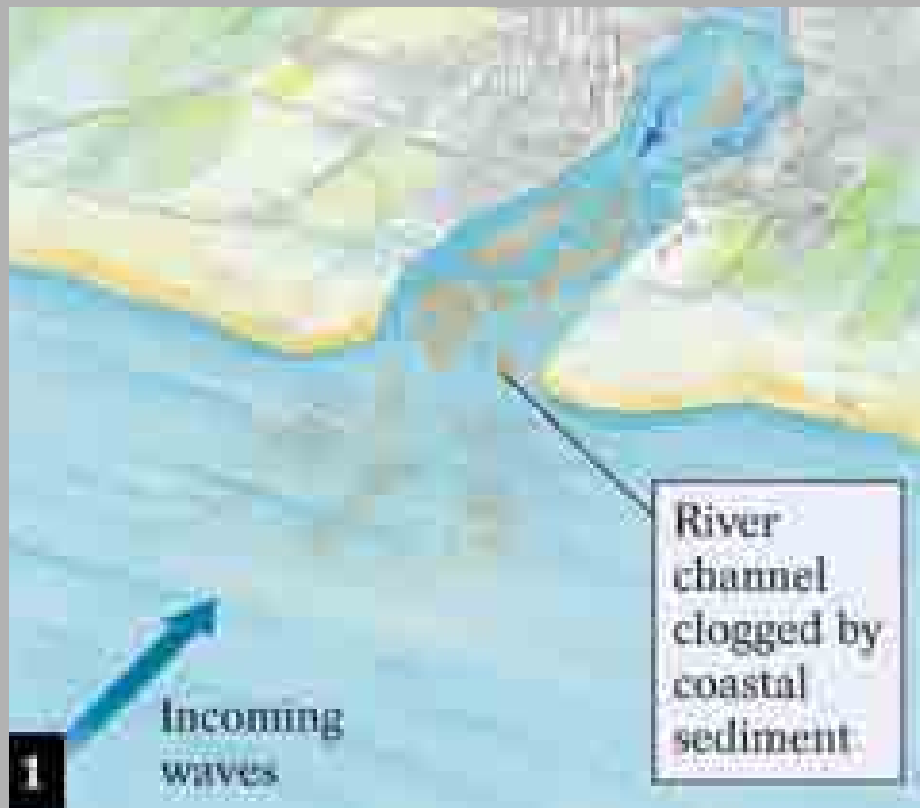
Wicander and Monroe (2002)

Mitigation of beach erosion

- Jetties – these have caused some of the worst examples of beach erosion. Modern structures built perpendicular to the shoreline include sand bypassing works designed to pump sand around the structure

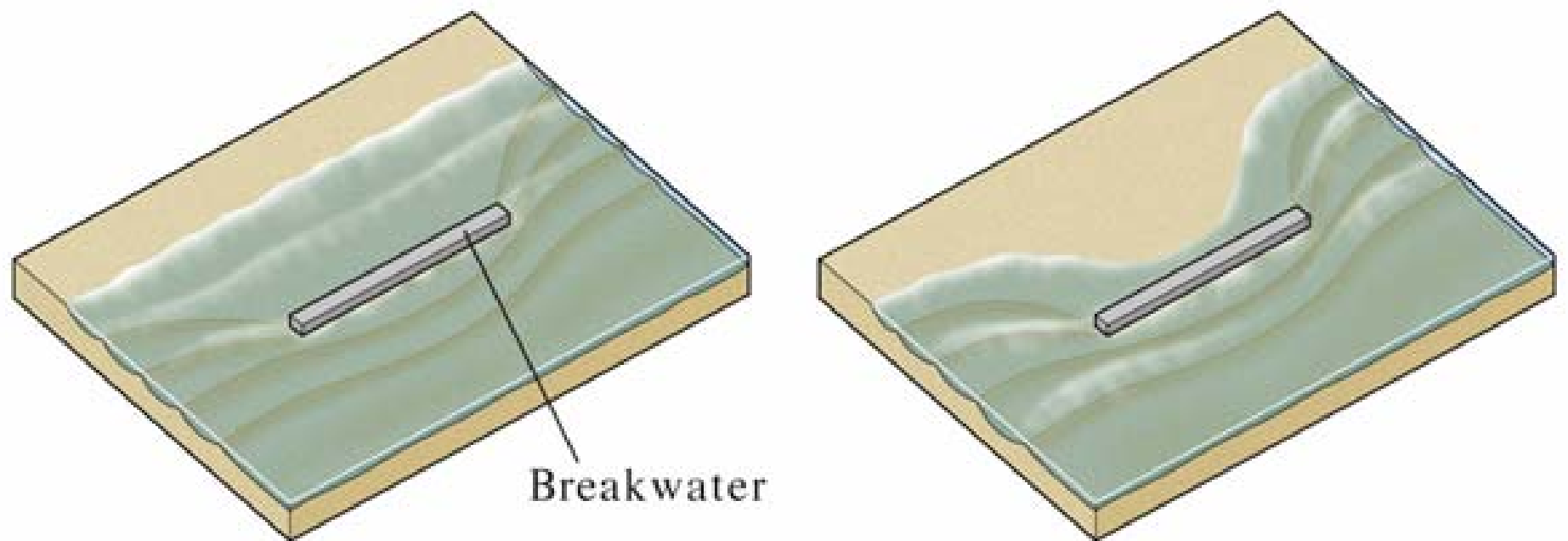


Why build jetties?



Chernicoff & Whitney (2002)

Breakwaters



Marshak (2002)

Mitigation of beach erosion

- Beach 'nourishment' – in areas where significant beach erosion has occurred but developer or tourist requirements demand a beach, beach replacement may be undertaken. In the late '70s creation of a new beach 10 miles long and 300 feet wide in Miami Beach cost \$65 million.
- Unfortunately, artificially nourished beaches are short lived as the sand is typically finer than the natural sand and they tend to have steeper shorefaces making them more susceptible to wave action
- In addition, unless the cause of the beach erosion is dealt with the new beach will be eroded away requiring constant replenishment. A 1982 beach replenishment in Ocean City at a cost of \$5.2 million lasted only 2.5 months.

Smart design

- Foundations rest on bedrock
- Bulkhead minimises wave erosion



Pipkin and Trent (1997)



Westhampton beach, NY: Pipkin and Trent (1997)

Effects of erosion



Marshak (2002)