Coastal Landforms and Processes

- Waves, Tides and Shallow Water Processes
- Littoral Zone
- Beaches & Seasonal Cycles
- Barrier Islands
- Beach Ridges
- Spits
- Deltas
- Coastal Cliffs
- Marine Terraces
- Wave-Cut Scarps
- Sea Level Fluctuations
- Barrier Island Migration
- Coastal Diversity

Hawaiian coastline

Photo source: SCGS

Factors Influencing Coastal Geomorphology

Wind	direct influence:	saltation, dunes/blowouts
	indirect influence:	wave generation, ocean circulation setup - setdown

Seiches: lakes, estuaries, small seas, created by changes in barometric pressure, violent storms and tides.

Storms: tropical, extratropical (Noreasters), storm surges, winds, waves

Biology: reef builders, filter feeders, grasses/wetlands etc.

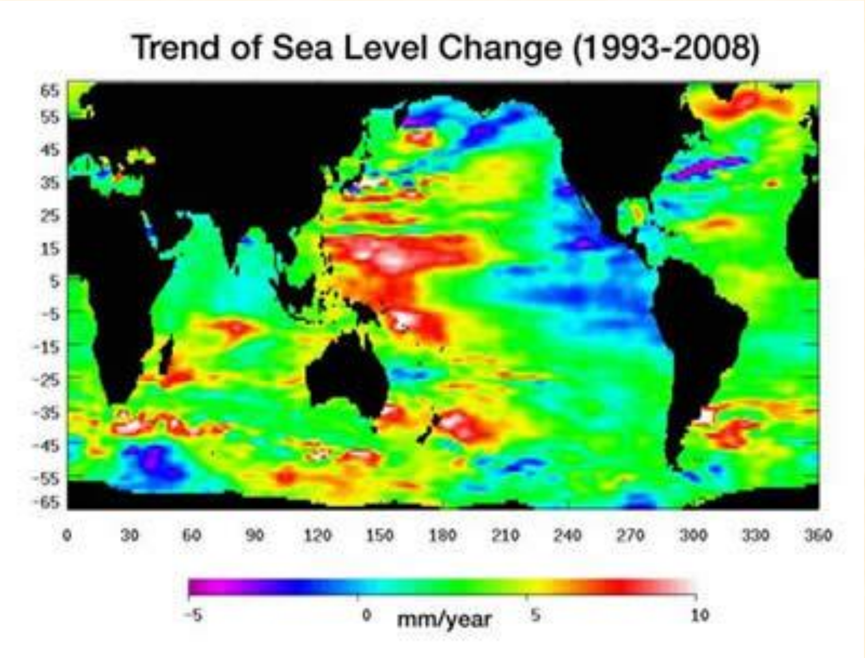
Sea Level Changes

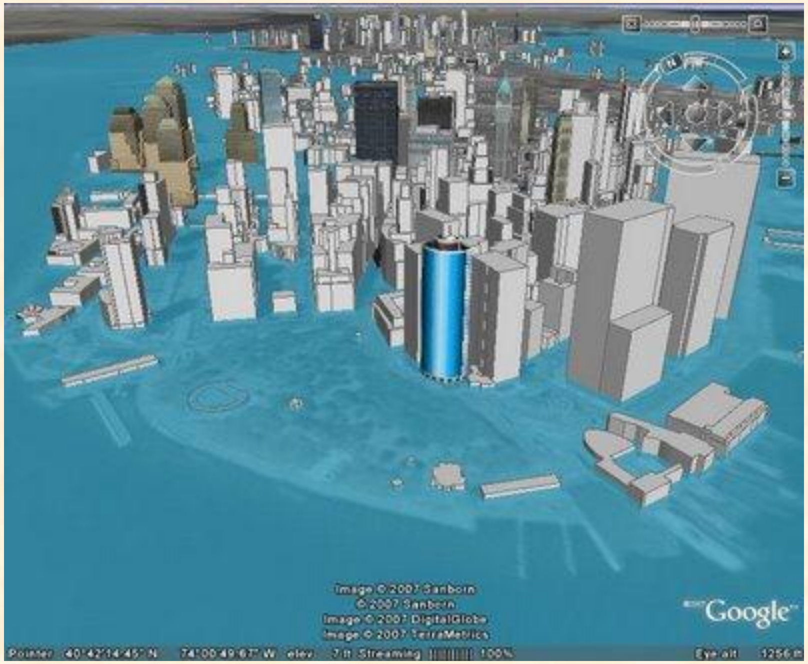
Sea level changes are easily determined from water level gauges.

Few gauges have data extending back 50/100 years

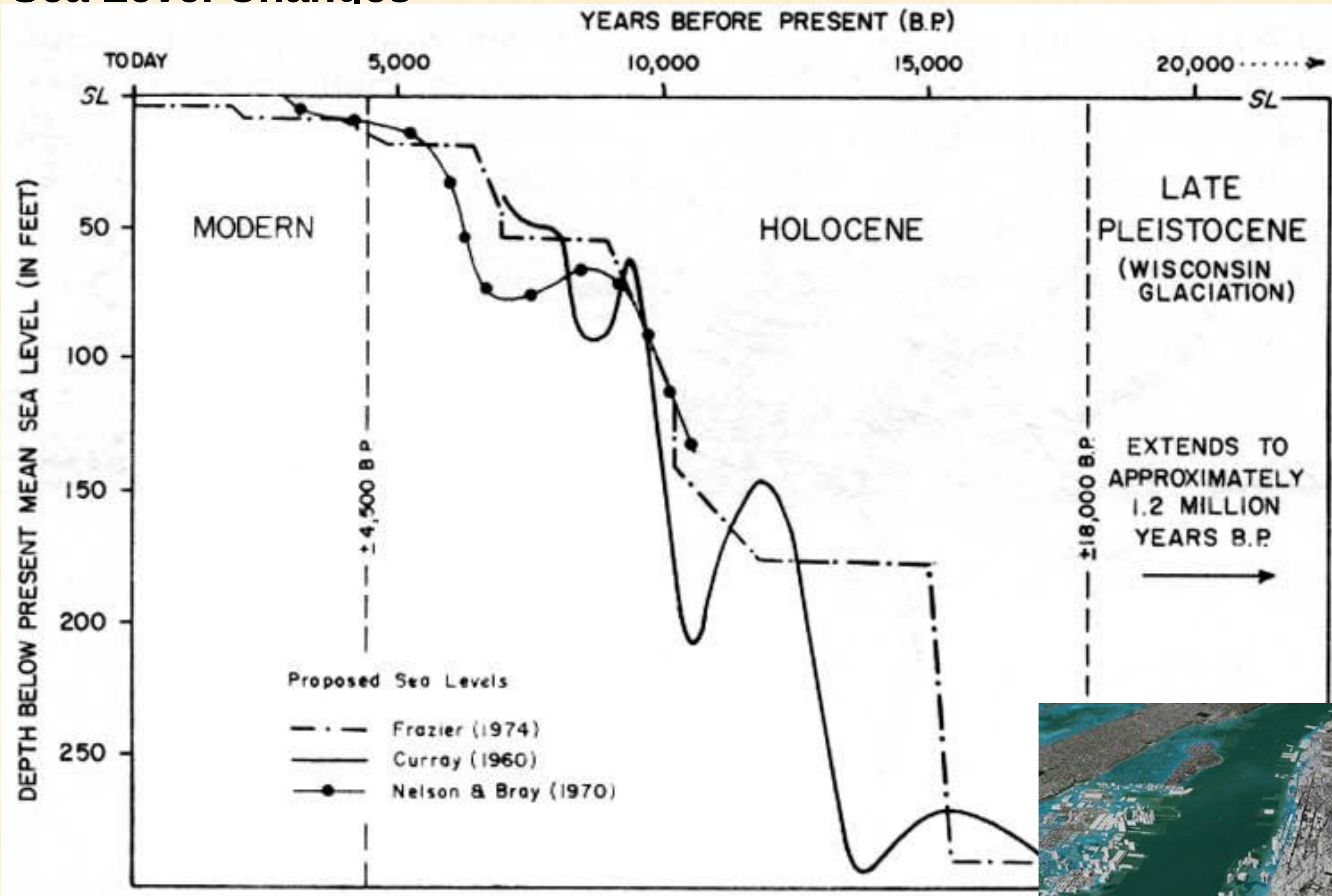
Eustatic: global sea level changes associated with the addition or removal of water (15 cm/century – 23 cm/century)

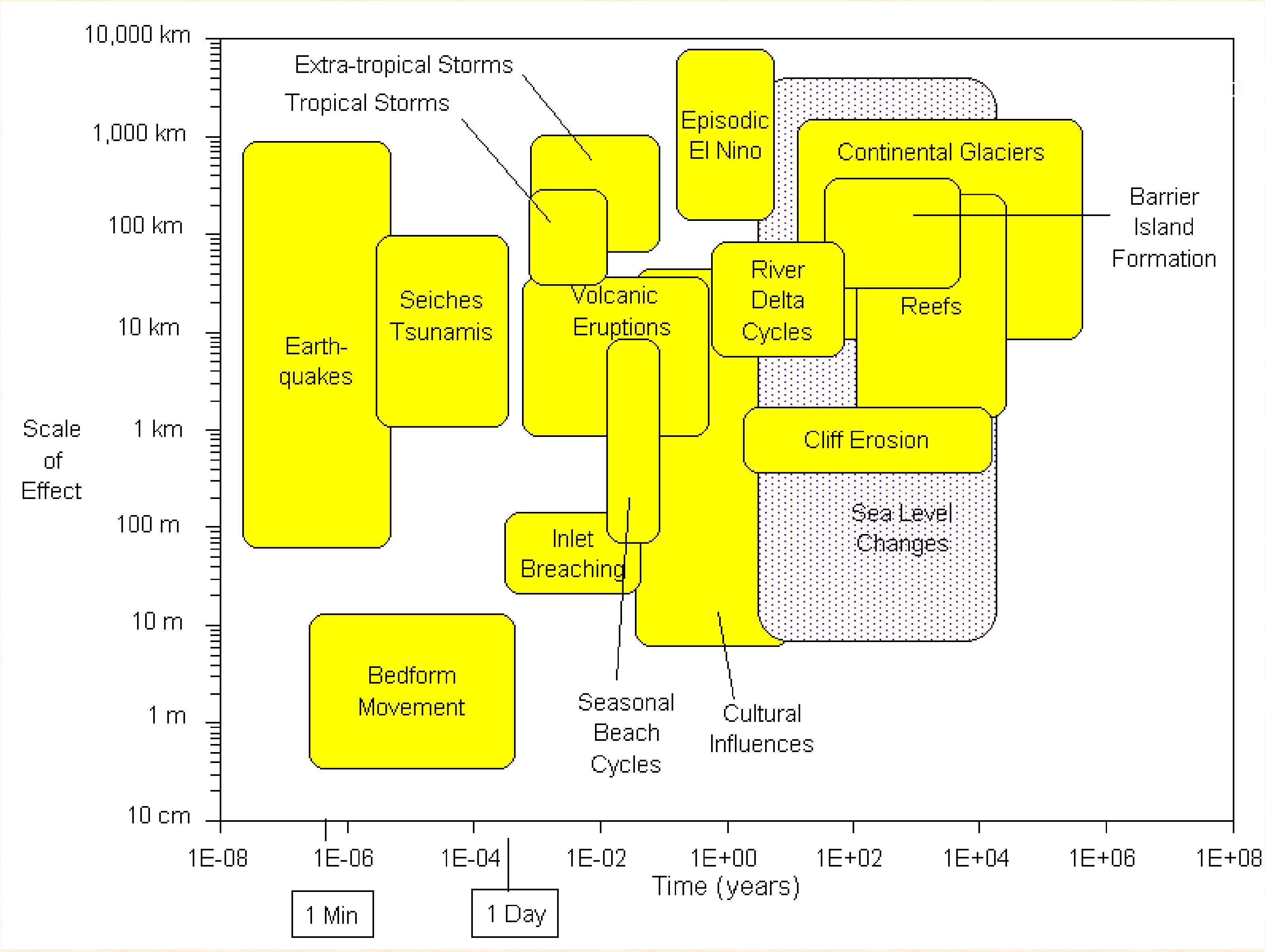
Relative: sea level changes relative to a local datum, incorporates tectonic influences





Sea Level Changes

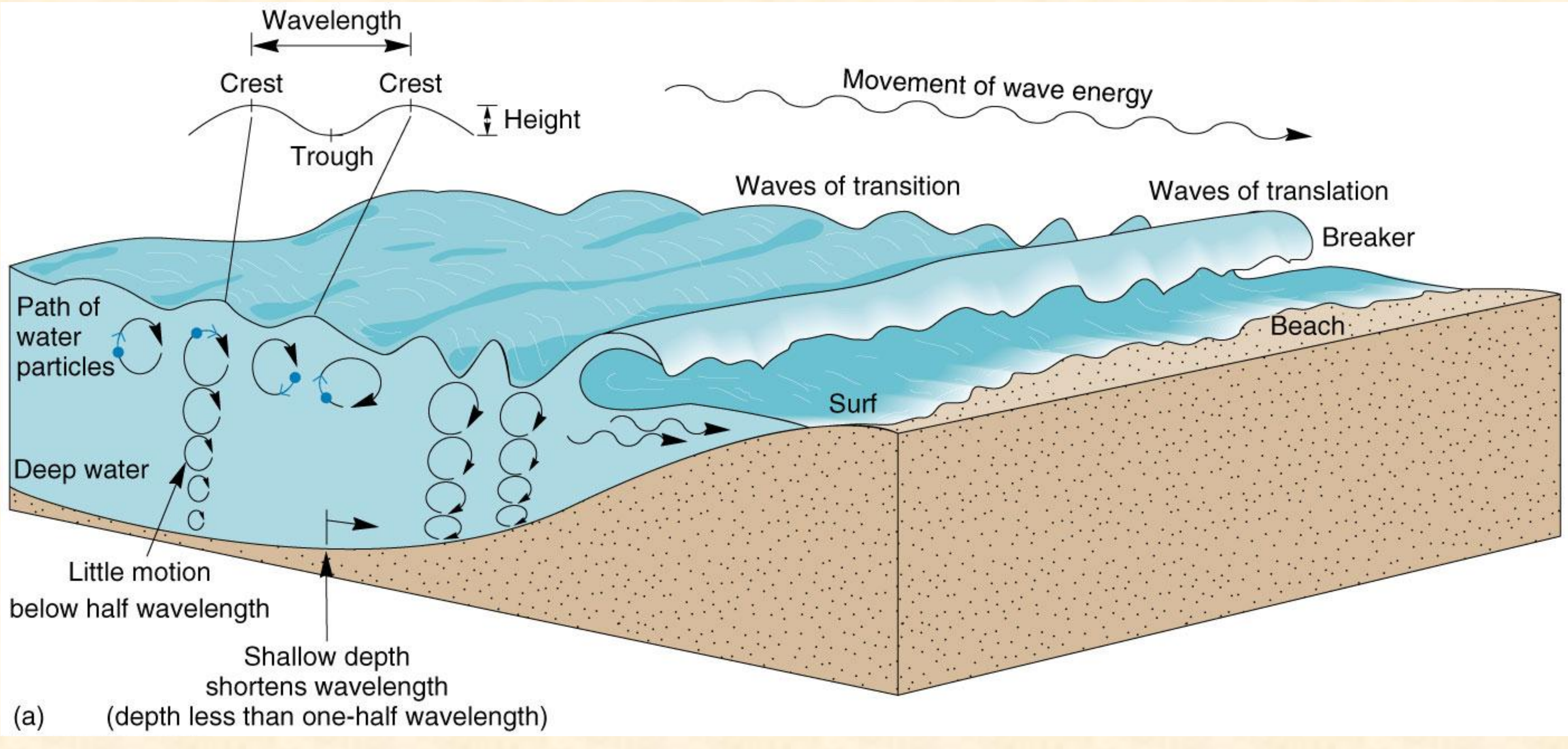




Features and landforms range in size from centimeters to kilometers and are formed or modified over time scales of minutes to millennia.

Wave Formation:

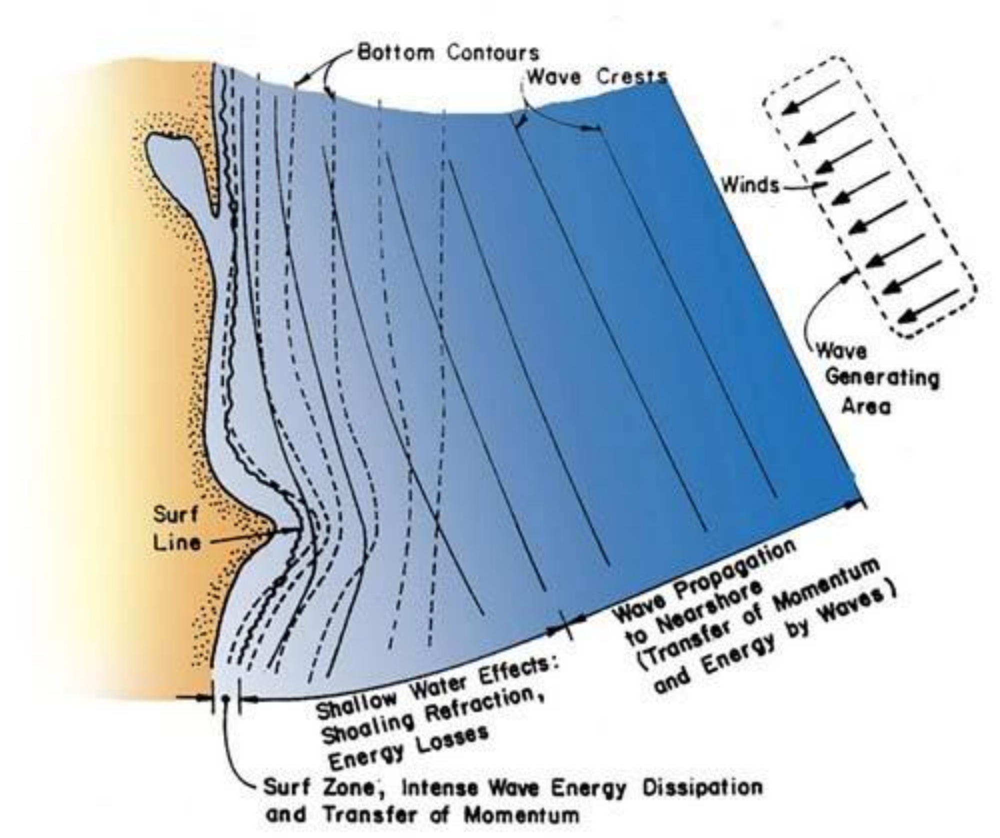
- Speed, fetch, duration
- Fully developed sea state
- Dispersion



Shallow Water Processes: shoaling, refraction, diffraction, reflection, breaking, wave(wind) setup/setdown

Wave Refraction: changes in the direction of wave propagation due to along crest variations in wave speed

Wave Rays: lines drawn perpendicular to the crest of the wave in the direction of wave propagation



Wave Refraction

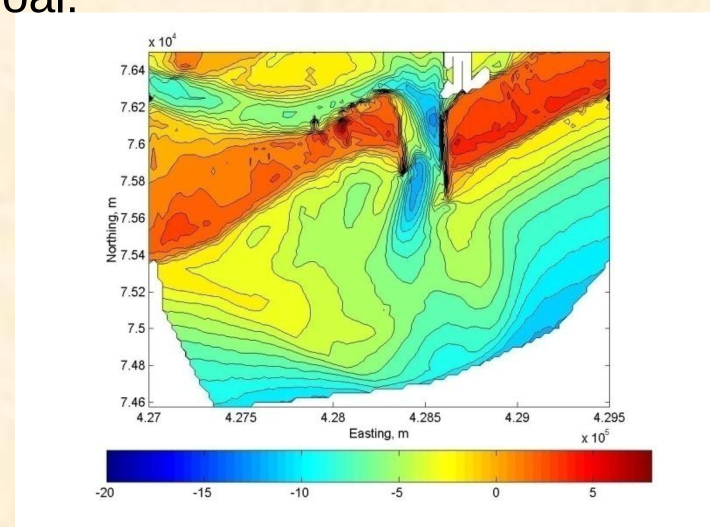
Parallel Contours: refraction results in wave rays approaching normal to shoreline = (wave crests parallel to shoreline (a))

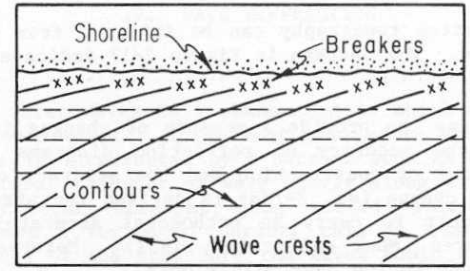
Submarine Ridge: focusing of wave energy toward the ridge (b)

Submarine Canyon: spreading of wave energy throughout the depression (c)

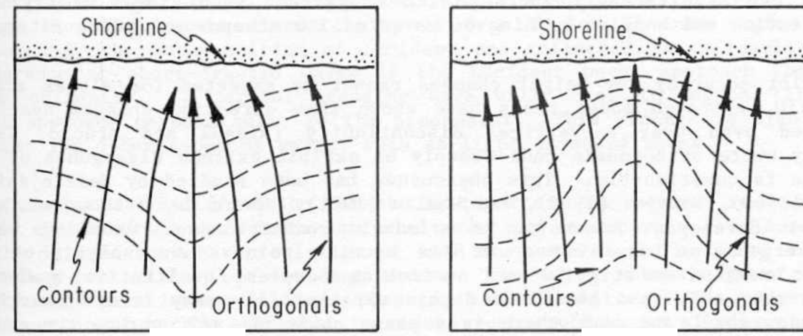
Headland: focusing of wave energy (d)

Ebb-Shoal:



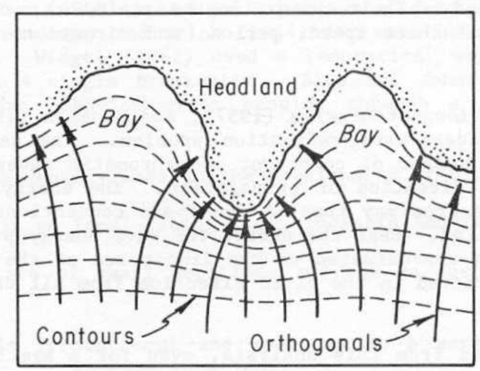


Fi (a) 3. Refraction along a straight beach with parallel bottom contours.



(b) (c)

Figure 2-24. Refraction by a submarine ridge (a) and submarine canyon (b).



Figur (d) Refraction along an irregular shoreline.

Wave Diffraction: bending of wave crests (changes in direction) due to along crest gradients in wave height

Figure 11. Mound diffraction structure as constructed at Grays Harbor, WA (2000)

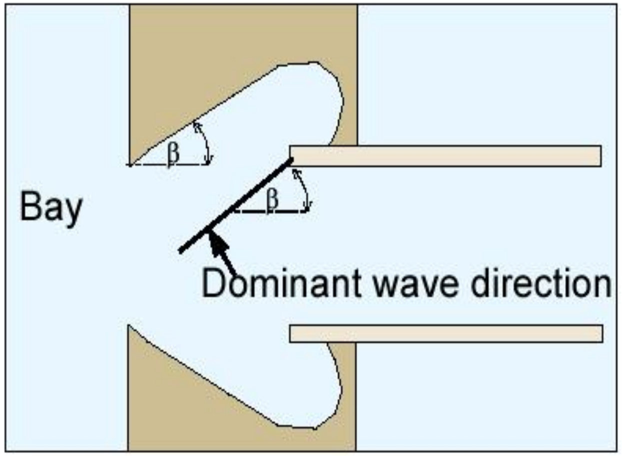
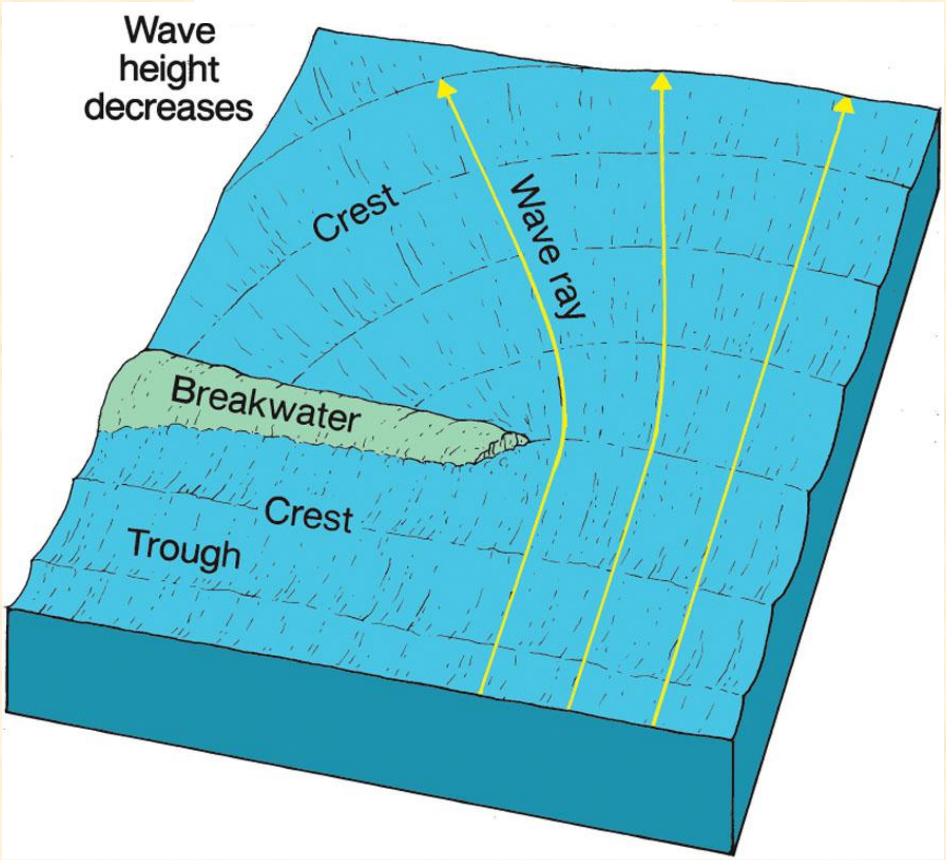
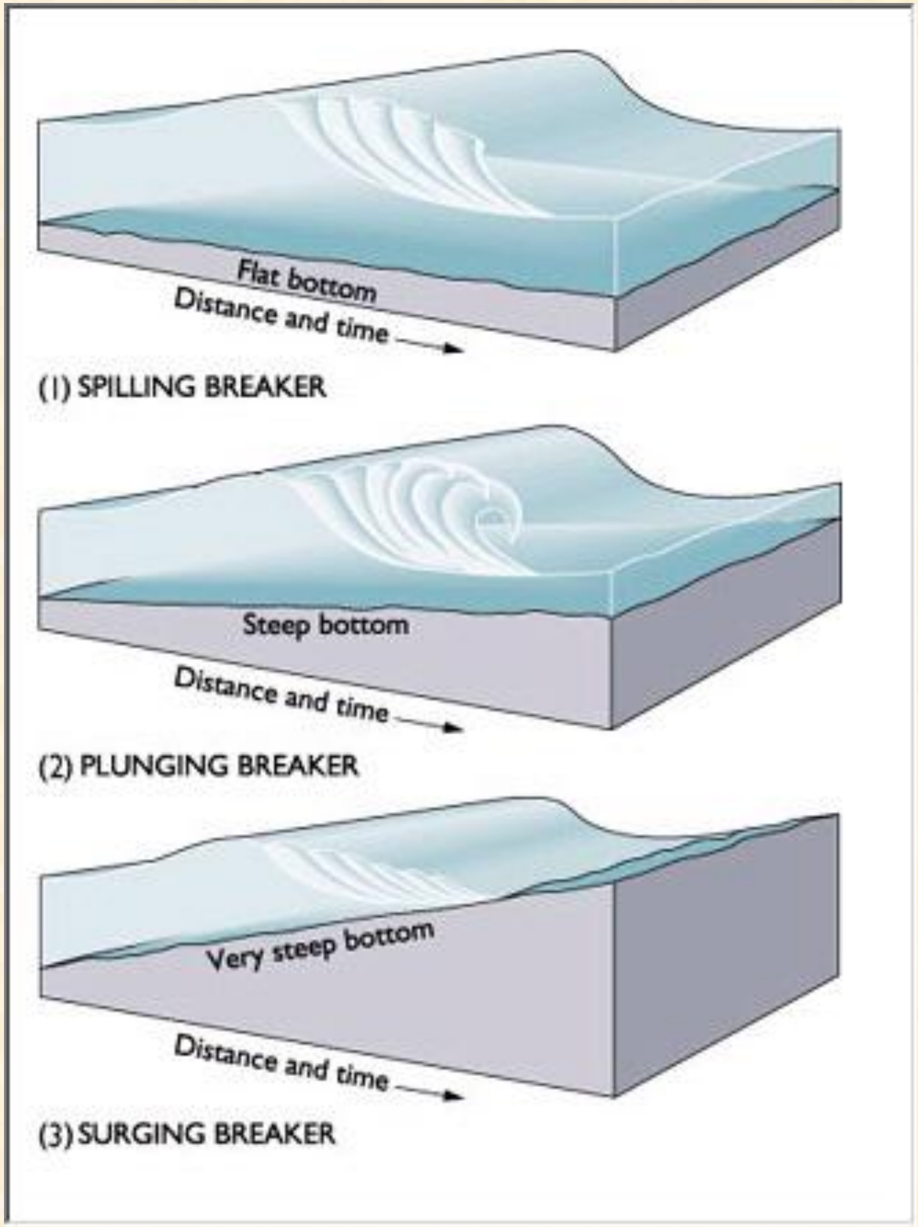


Figure 12. Equilibrium inner-bank erosion showing dominant wave angle and shoreline orientation angle, β



Wave Breaking



Surf Similarity Parameter

Deep Water Wave Height

$$\xi_o = \tan\beta \left(\frac{H_o}{L_o} \right)^{-\frac{1}{2}}$$

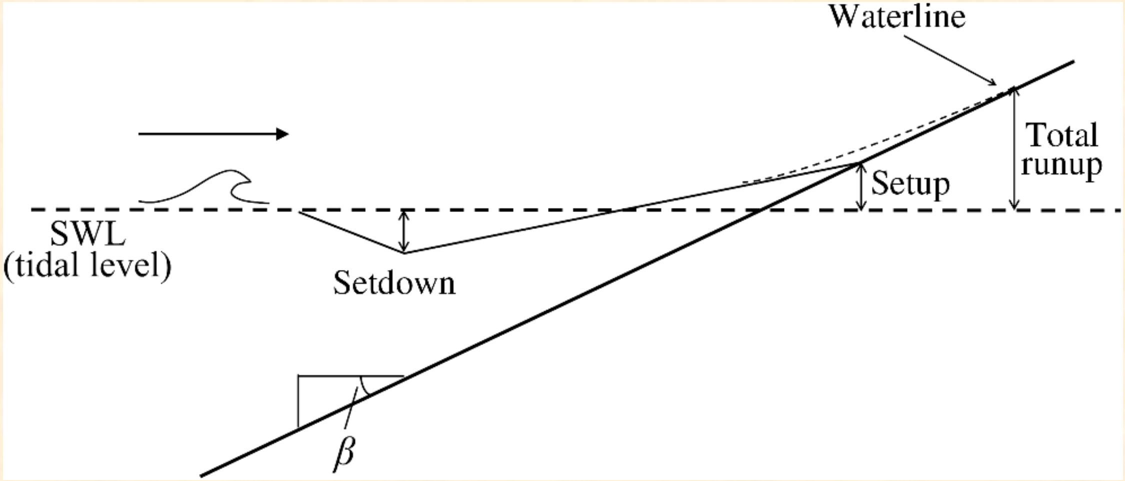
Beach Slope

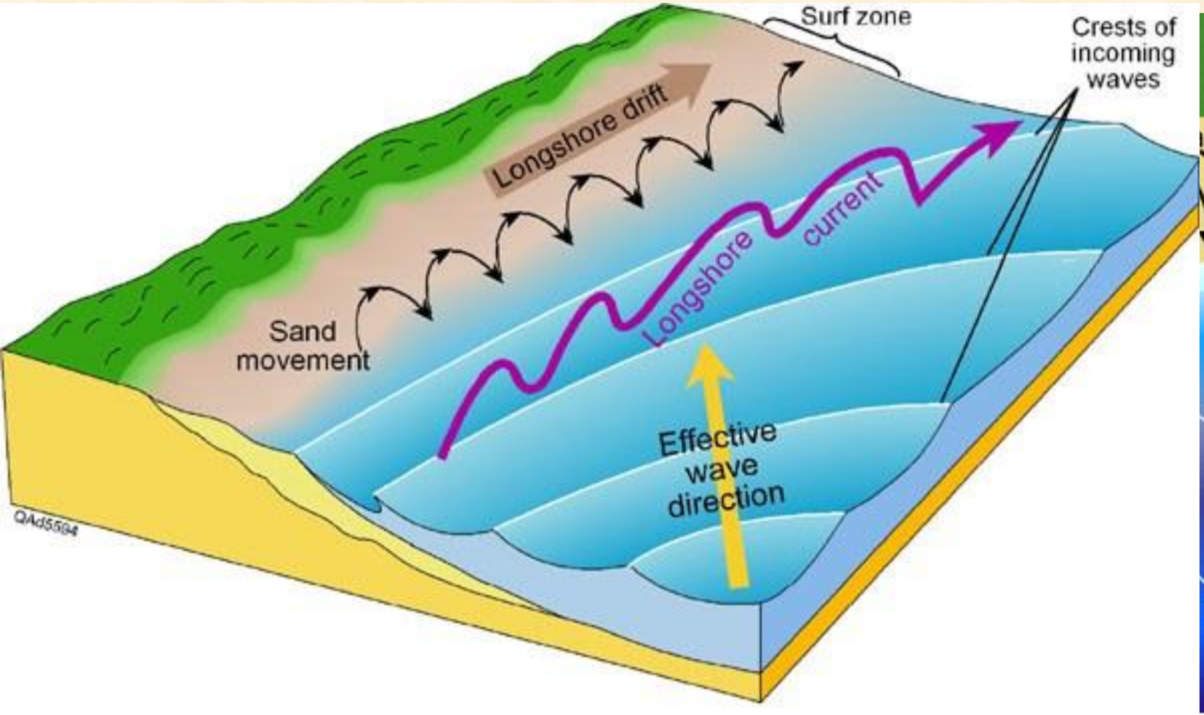
Deep Water Wave Length

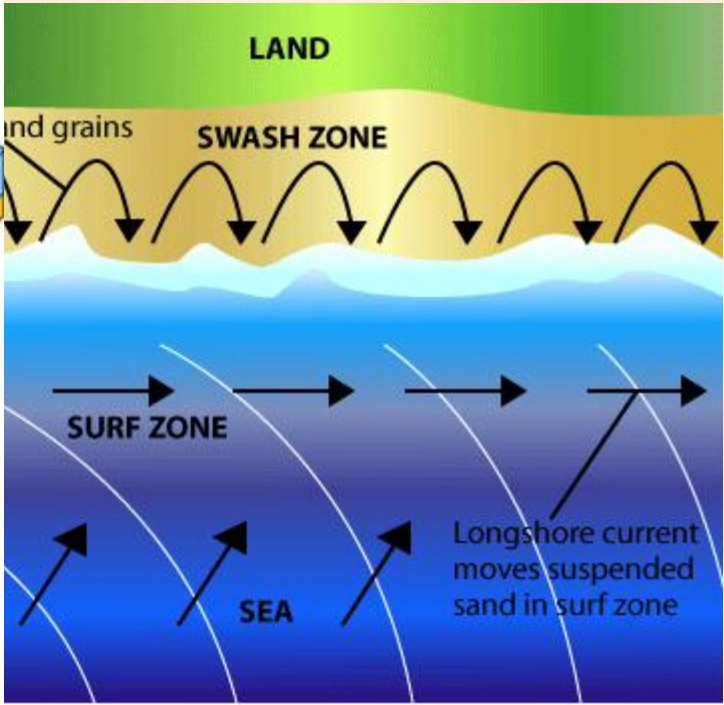
Surging/collapsing	$\xi_o > 3.3$
Plunging	$0.5 < \xi_o < 3.3$
Spilling	$\xi_o < 0.5$

Nearshore Currents:
- longshore
- cross-shore
- rip currents
- undertow

wave/wind setup

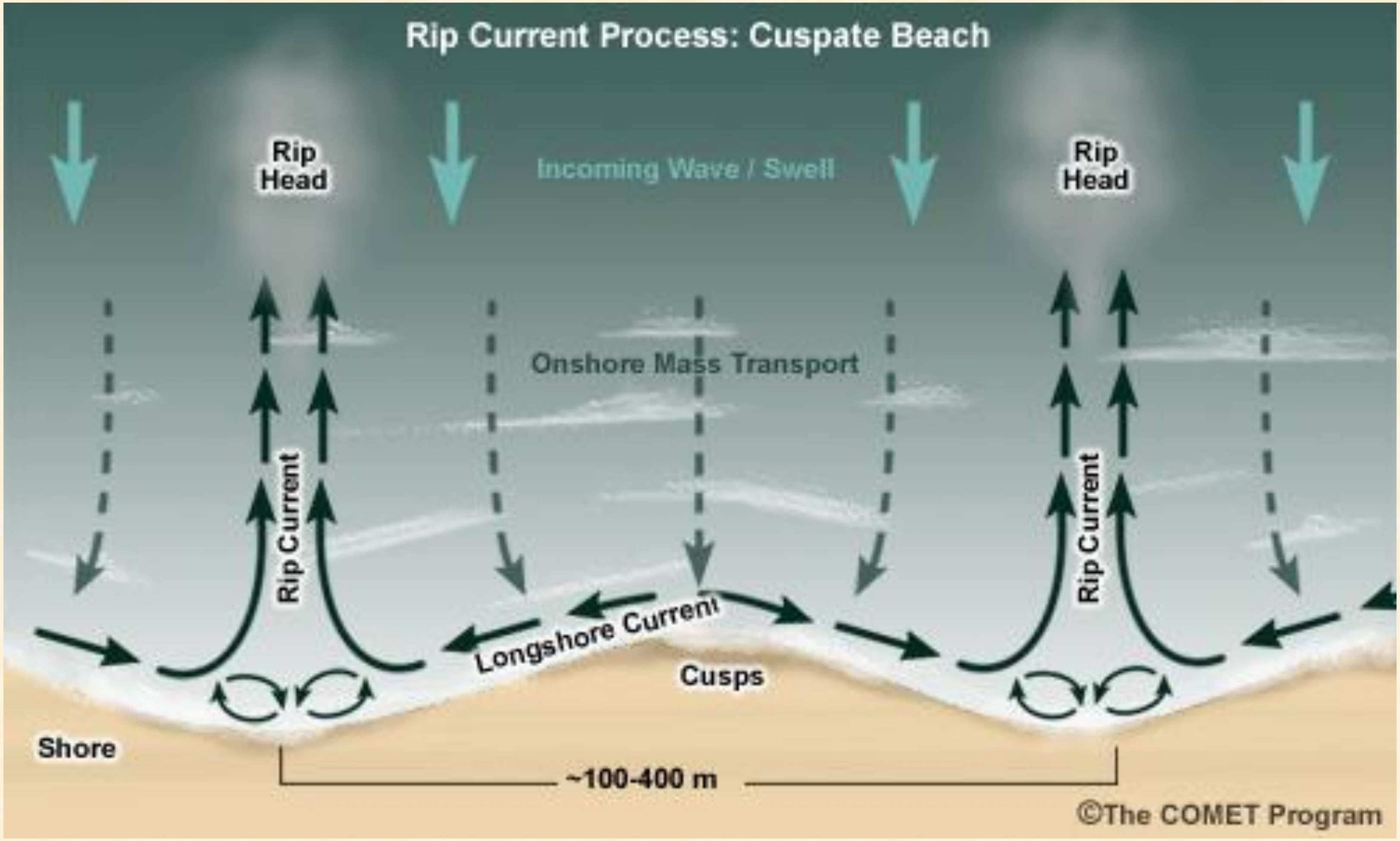




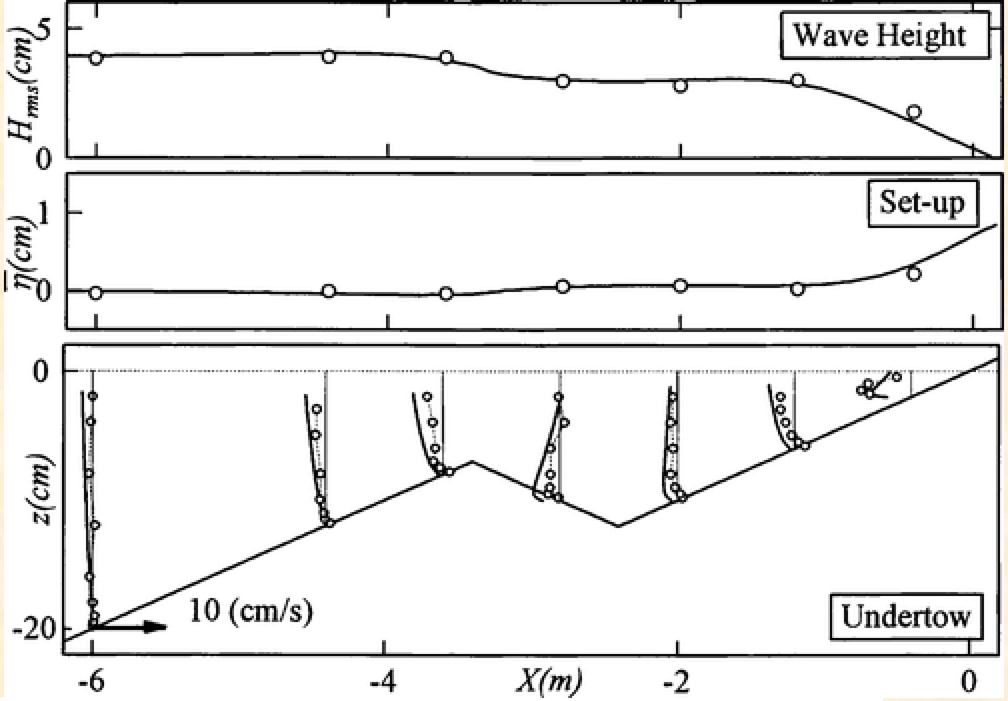


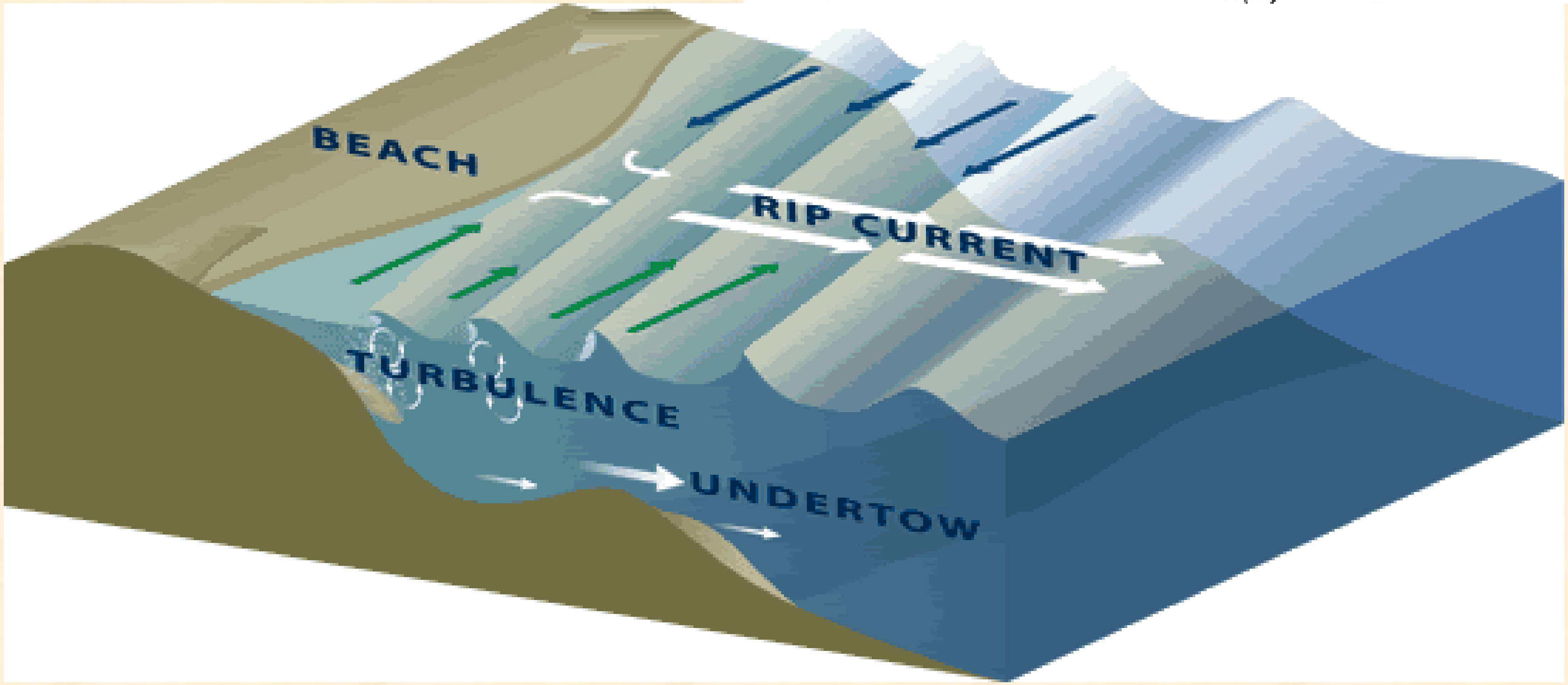
Rip Current

- bathymetric control
- hydrodynamic control
- relation to morphology

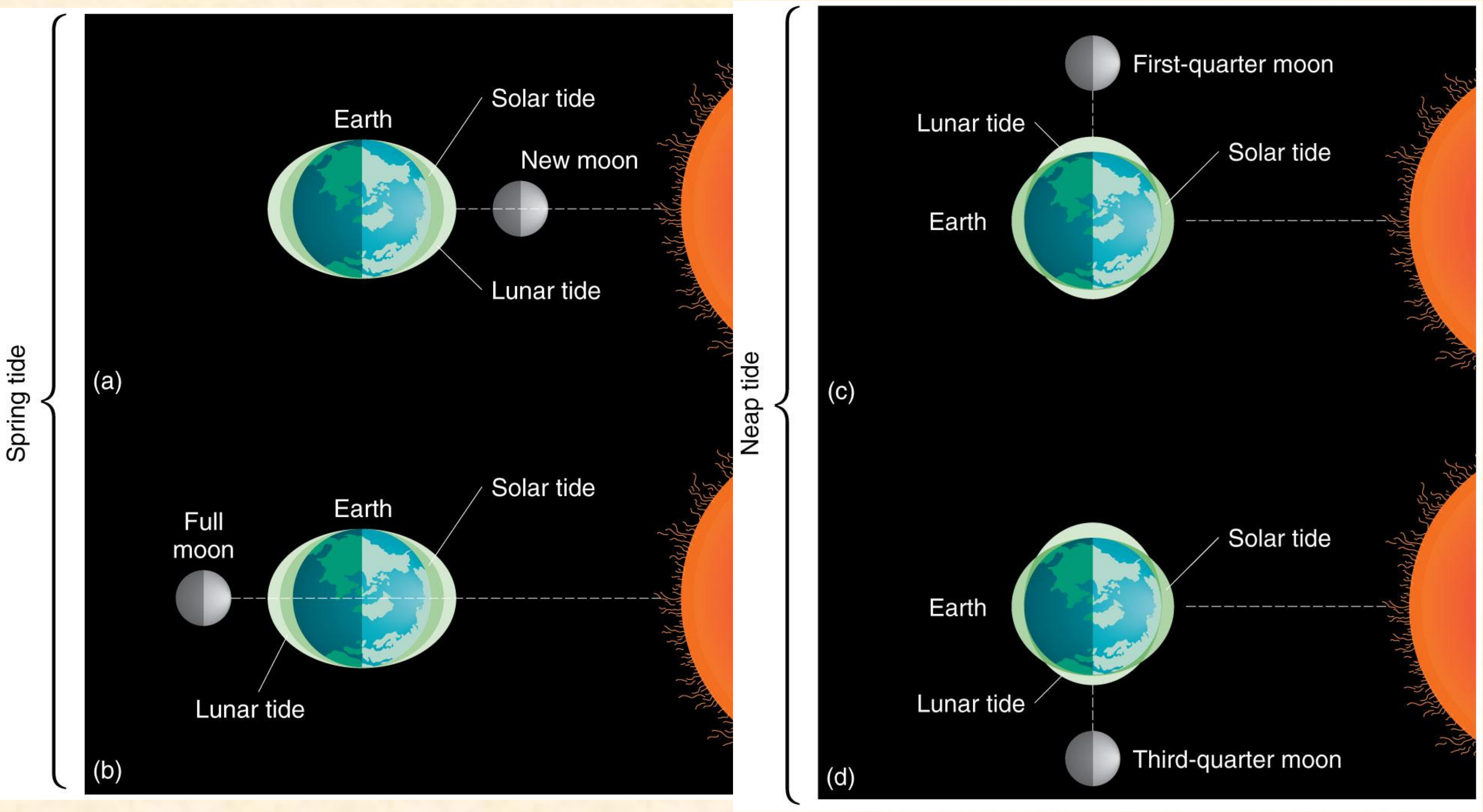


Undertow:
- xshore pressure gradient
- velocity decreases offshore
- deposition of material
- sand bar formation





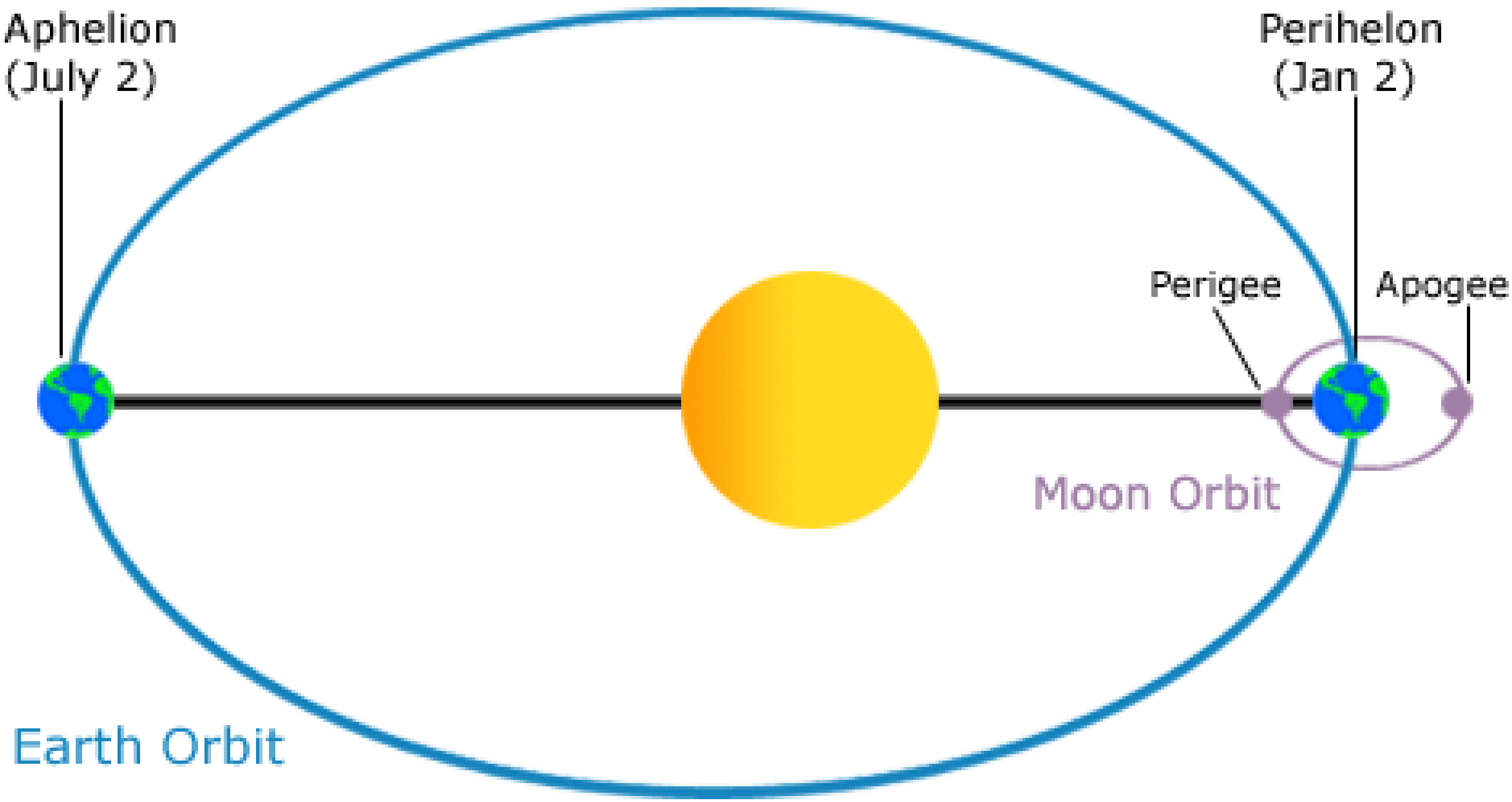
Tidal forces



Tides enhanced during full Moon and new Moon

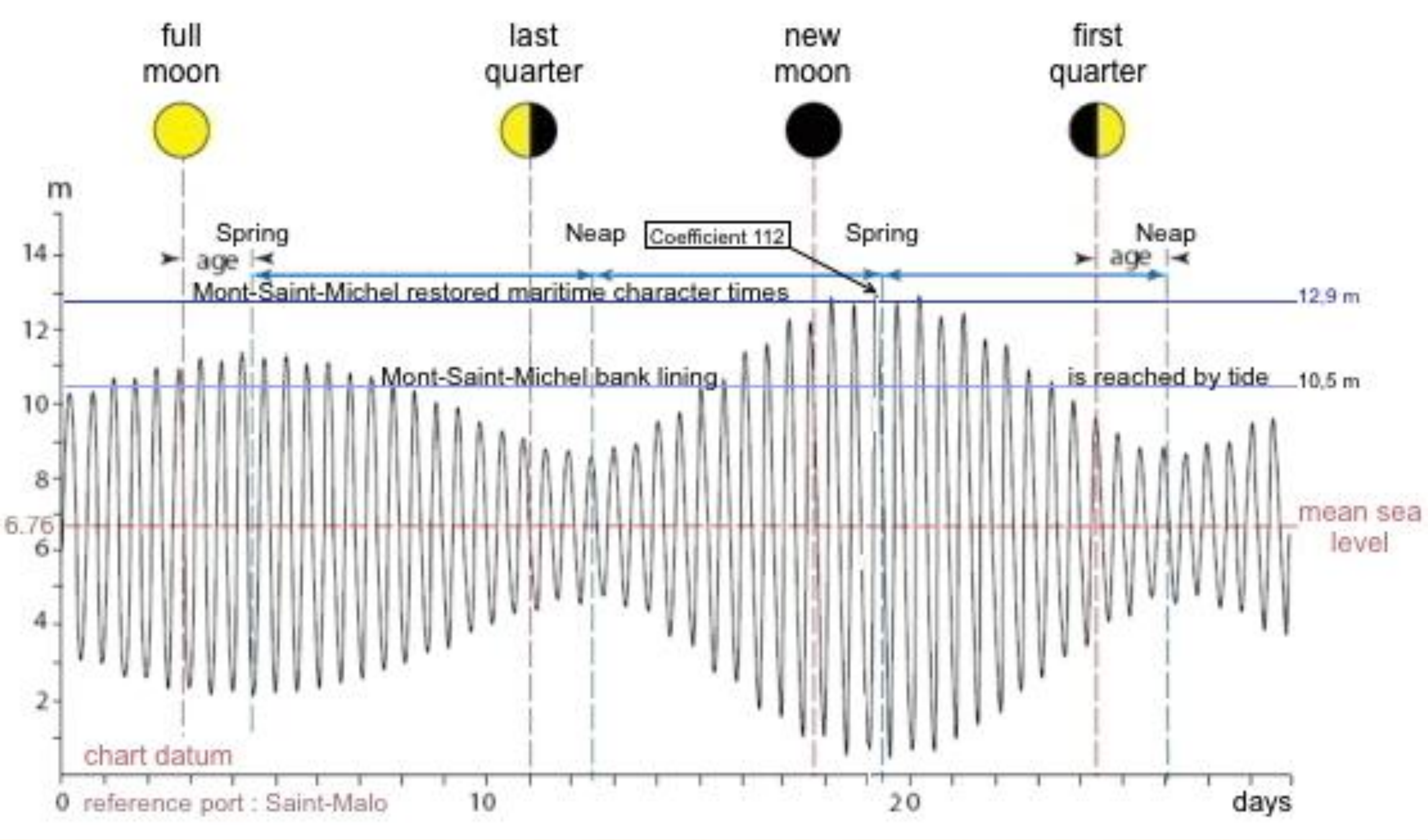
Sun-Moon-Earth closely aligned

Influence of Perigee, Apogee, Perihelion and Aphelion on the Earth's Tides



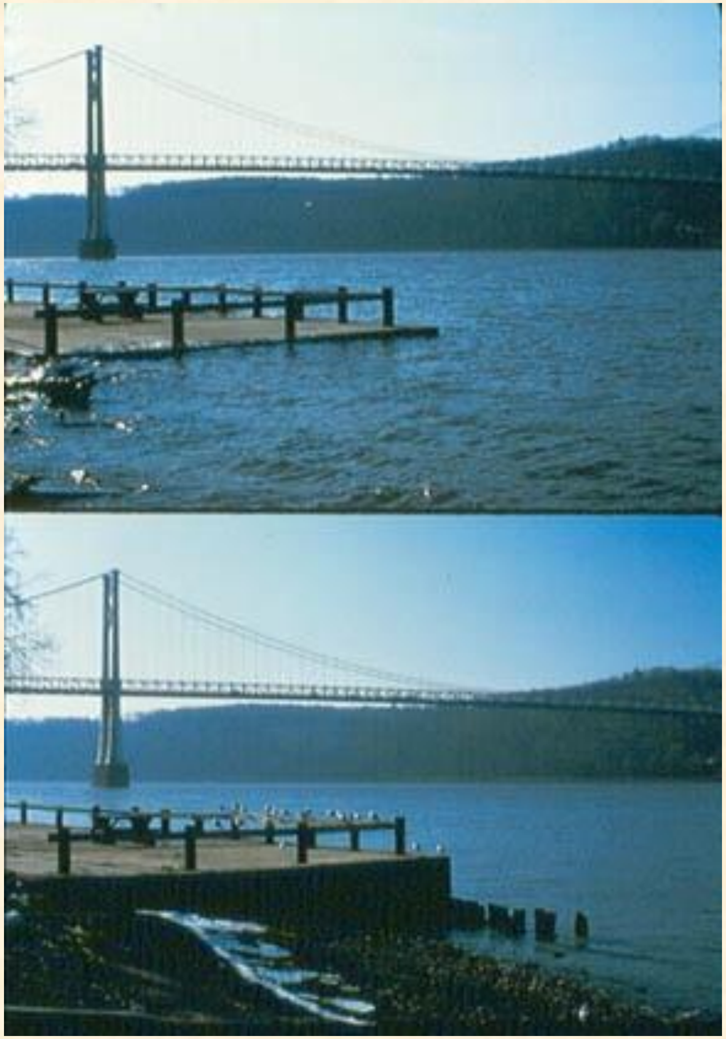
Stronger for perigee and perihelion

Lunar Cycle



full moon
last quarter
new moon
first quarter
m
Spring
age
Neap
Coefficient 112
Spring
Neap
age
Mont-Saint-Michel restored maritime character times
12,9 m
Mont-Saint-Michel bank lining
is reached by tide
10,5 m
mean sea level
6.76
14
12
10
8
6
4
2
chart datum
0
reference port : Saint-Malo
10
20
days

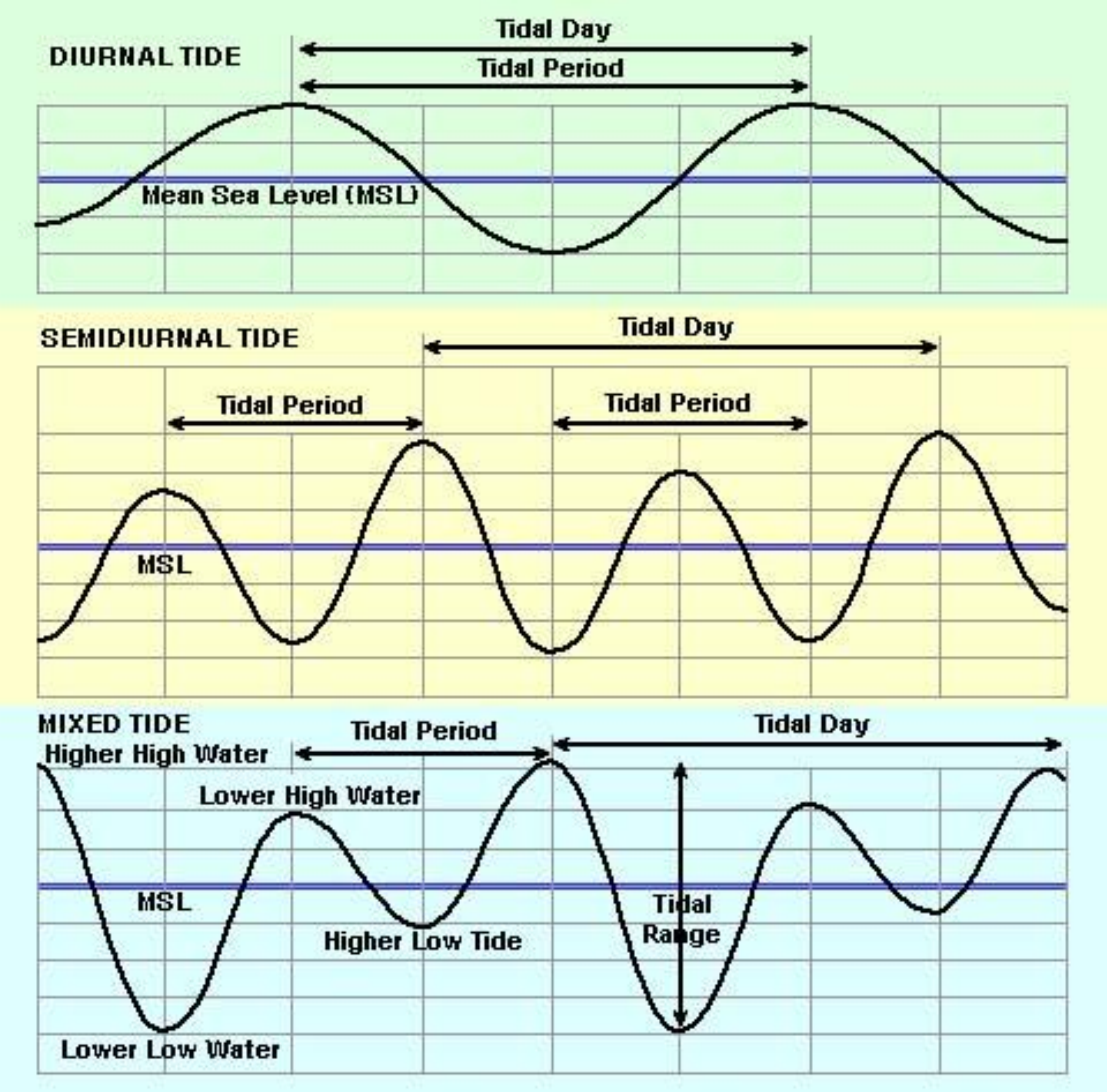
Tides: (diurnal, semi-diurnal, mixed)



- The periodic change in water level results in different parts of the foreshore being exposed to wave energy throughout the day. In regions with large tidal ranges, the water may rise and fall 10 m, and the shoreline may move laterally several kilometers between high and low water. **Different region of the intertidal zone are exposed to erosion and deposition**.

- tidal currents can erode and transport sediment. residual motions can be highly important and spatially asymmetric patterns of ebb and flood stages **may cause mass transport of both water and sediment**.

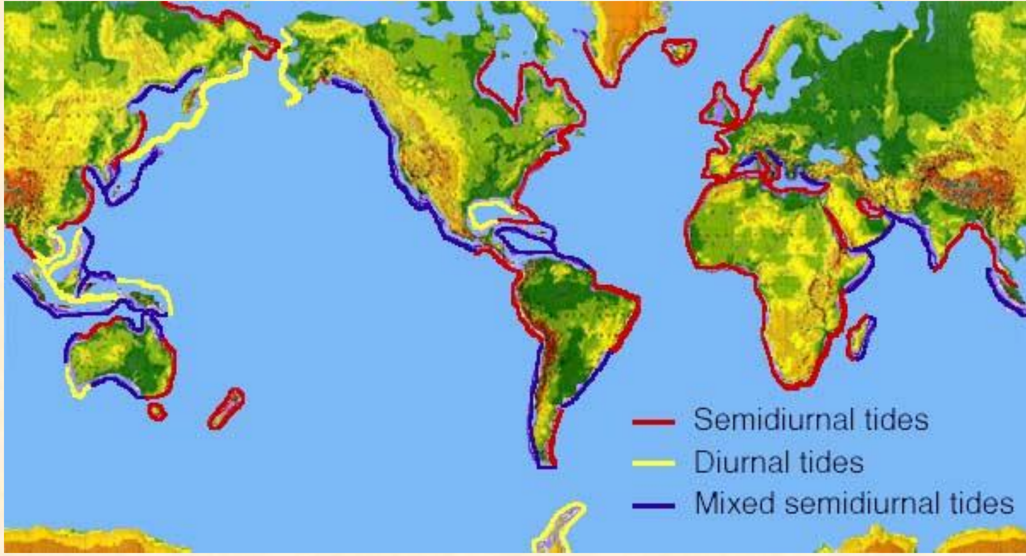
- tides cause the draining and filling of tidal bays, an important process related to the **cutting and migration of tidal inlets and the formation of flood- and ebb-tidal shoals in barrier coasts**.



DIURNAL TIDE
Tidal Day
Tidal Period
Mean Sea Level (MSL)
SEMIDIURNAL TIDE
Tidal Day
Tidal Period
Tidal Period
MSL
MIXED TIDE
Higher High Water
Tidal Period
Tidal Day
Lower High Water
MSL
Higher Low Tide
Tidal Range
Lower Low Water

Tidal Range Classification

Microtidal,	< 2 m.
Mesotidal,	2-4 m.
Macrotidal,	> 4 m.



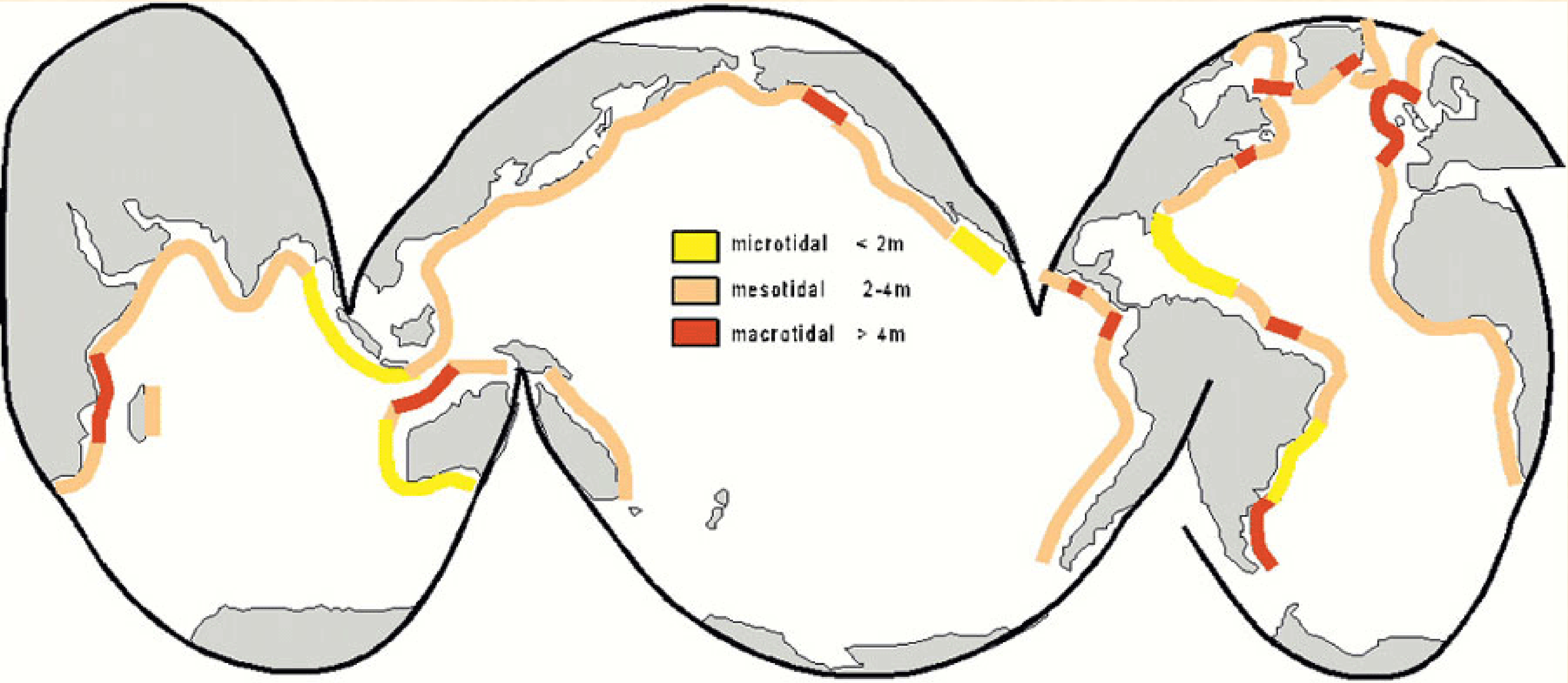
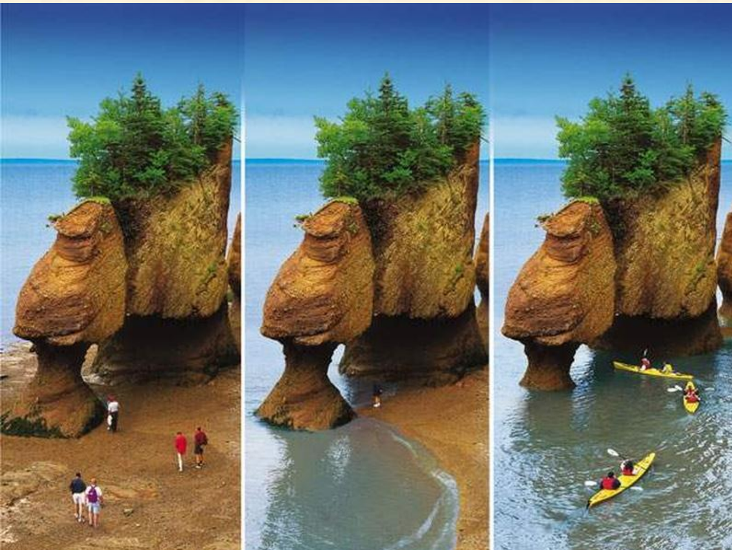
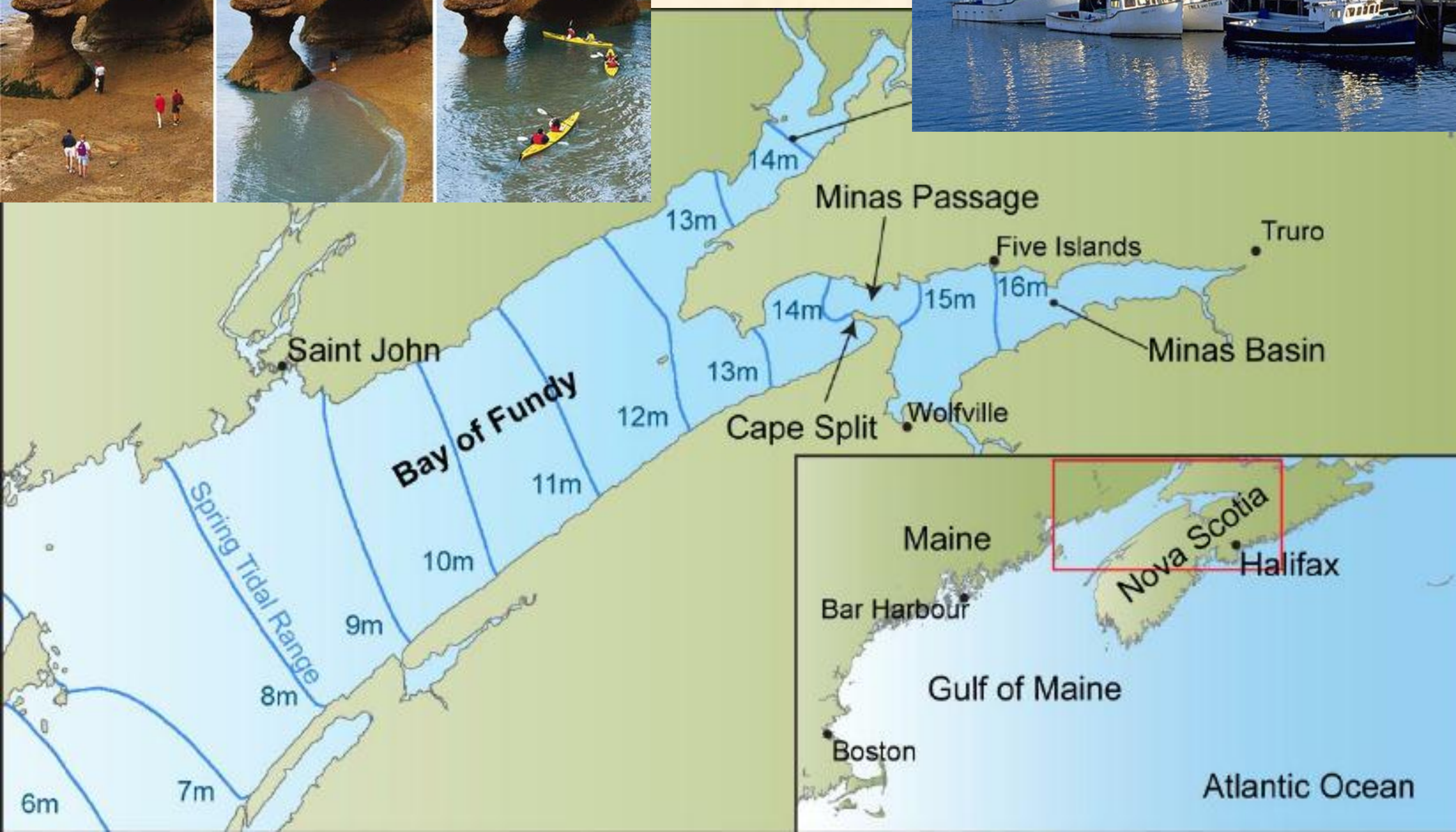


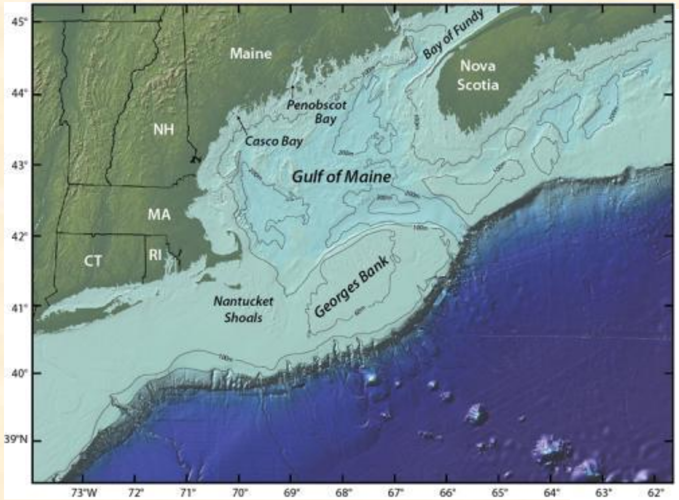
Figure Worldwide distribution of coastal tidal ranges.

Bay of Fundy, Nova Scotia





Georges Bank, Gulf of Maine



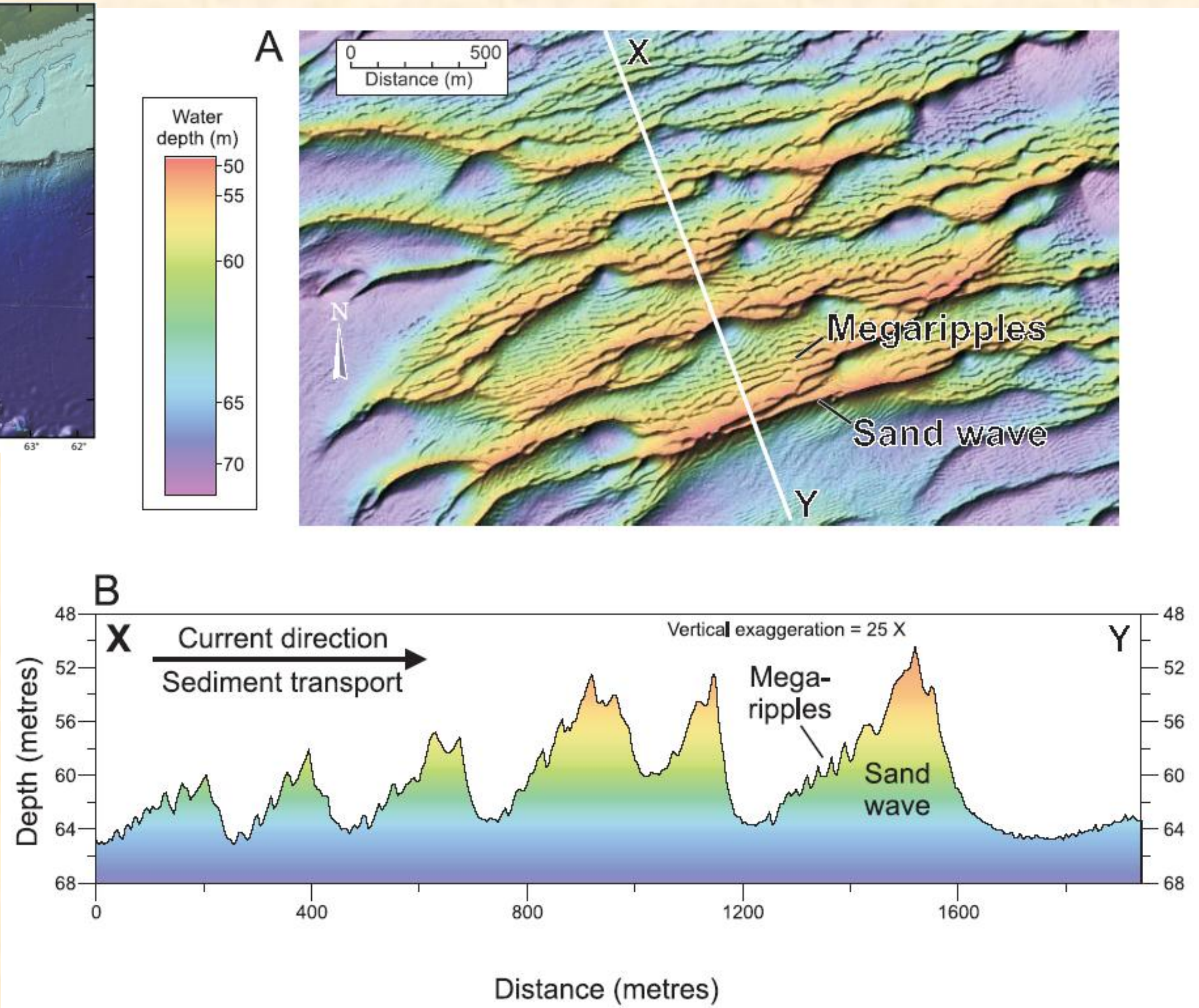


Figure 8. A) Detailed shaded relief bathymetry map showing sand waves and megaripples on Georges Bank; B) topographic cross section XY. Direction of current flow and sediment transport is from northwest to southeast. Meagripples occur on the up-current slope, or stoss, of the sand waves. Megaripples are less than 2 m in height; sand waves in this field reach 14 m in height.

- Hayes (1979) classification was based primarily on shores with low to moderate wave power and was intended to be applied to trailing edge, depositional coasts. Five shoreline categories were identified based on the relative influence of tide range versus mean wave height (Nummedal and Fischer 1978; Hayes 1979; Davis and Hayes 1984):

Tide-dominated (high).

Tide-dominated (low).

Mixed-energy (tide-dominated).

Mixed energy (wave-dominated).

Wave-dominated.

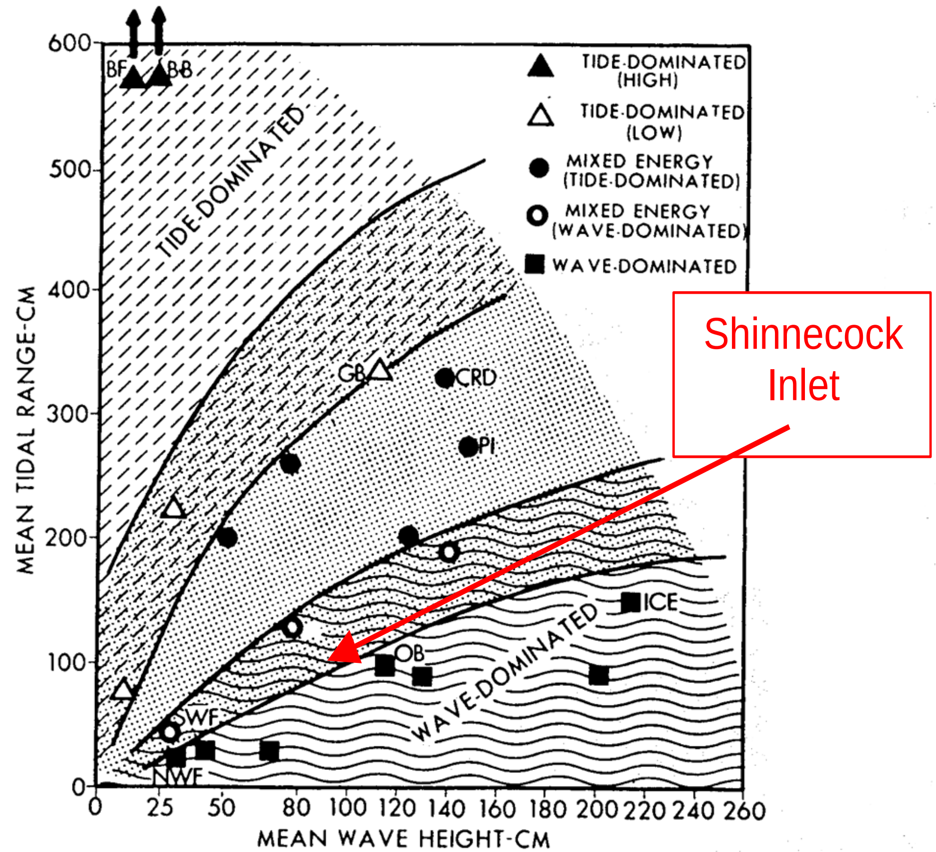


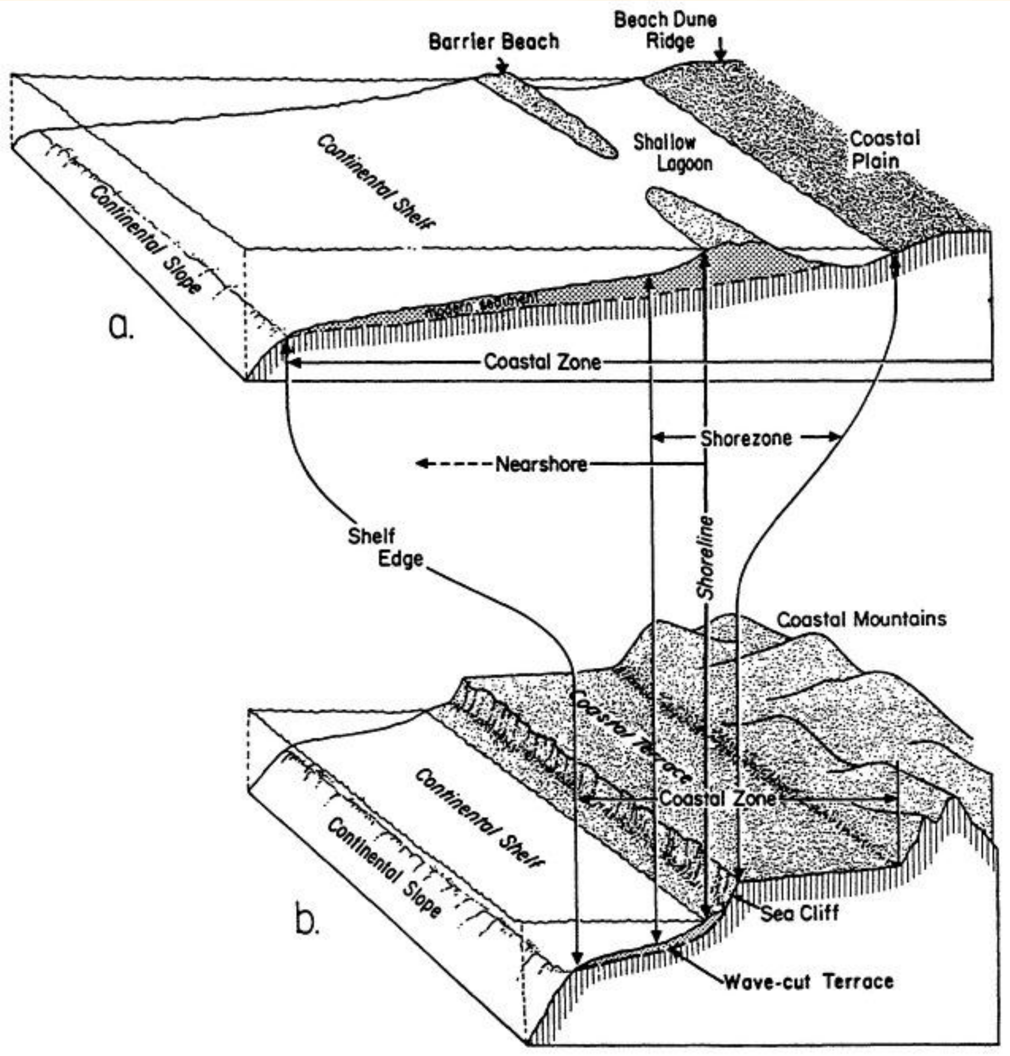
Fig. 15. Mean wave height vs. mean tidal range for 21 coastal plain shorelines. The areas are grouped into five morphological classes (indicated by different symbols). BF = Bay of Fundy; BB = Bristol Bay, Alaska; SWF = Southwest Florida; NWF = Northwest Florida; GB = German Bight; CRD = Copper River Delta, Alaska; PI = Plum Island, Mass.; OB = Outer Banks, N.C.; and ICE = Southeast Iceland.

***Coastal zone*:** is defined as the transition zone where the land meets water, the region that is directly influenced by marine hydrodynamic processes.

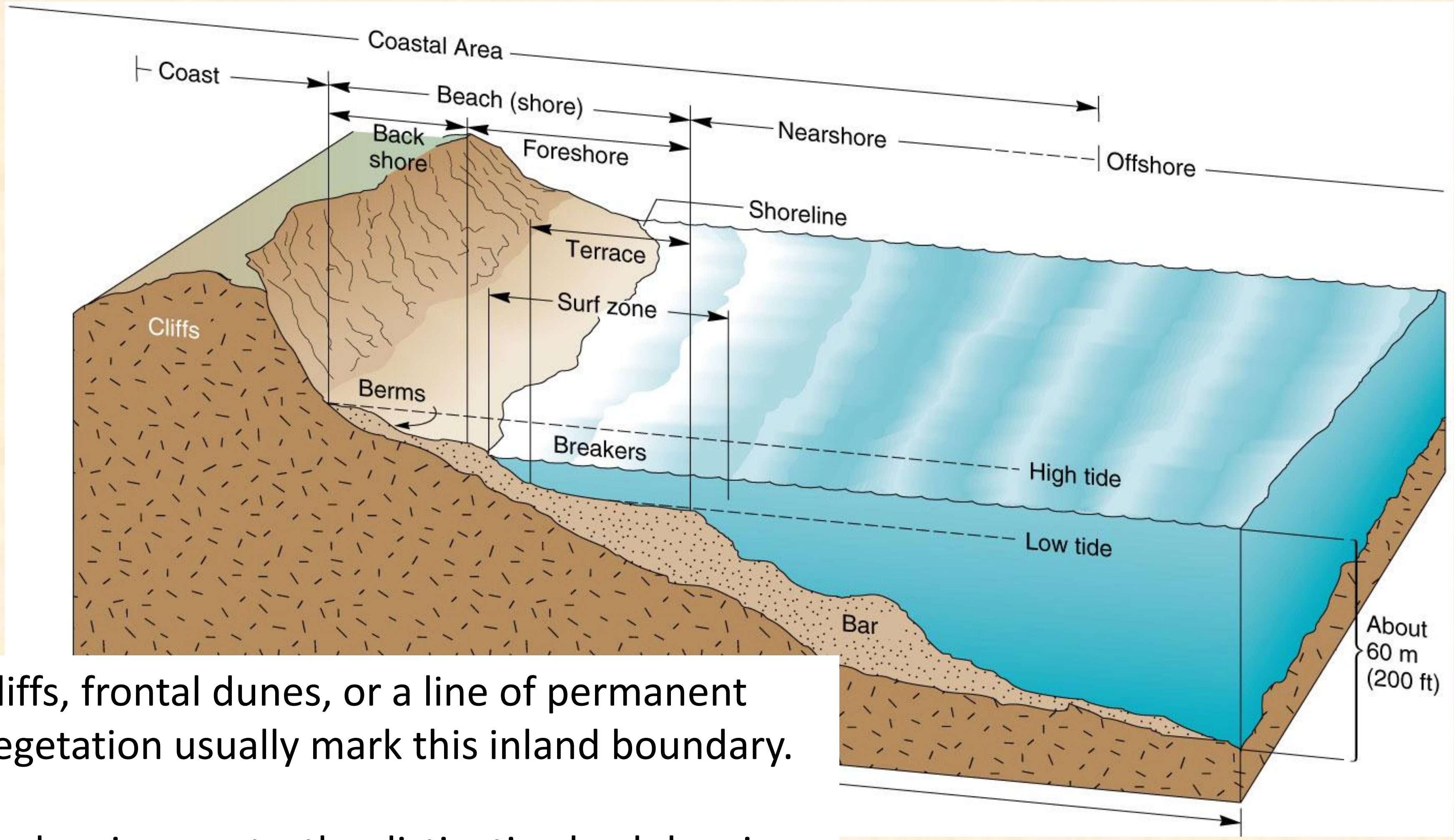
- The coastal zone extends offshore to the continental shelf break and onshore to the first major change in topography above the reach of major storm waves.

- The CZ is divided into four subzones:

  (1) Coast.
  (2) Shore.
  (3) Shoreface.
  (4) Continental shelf.

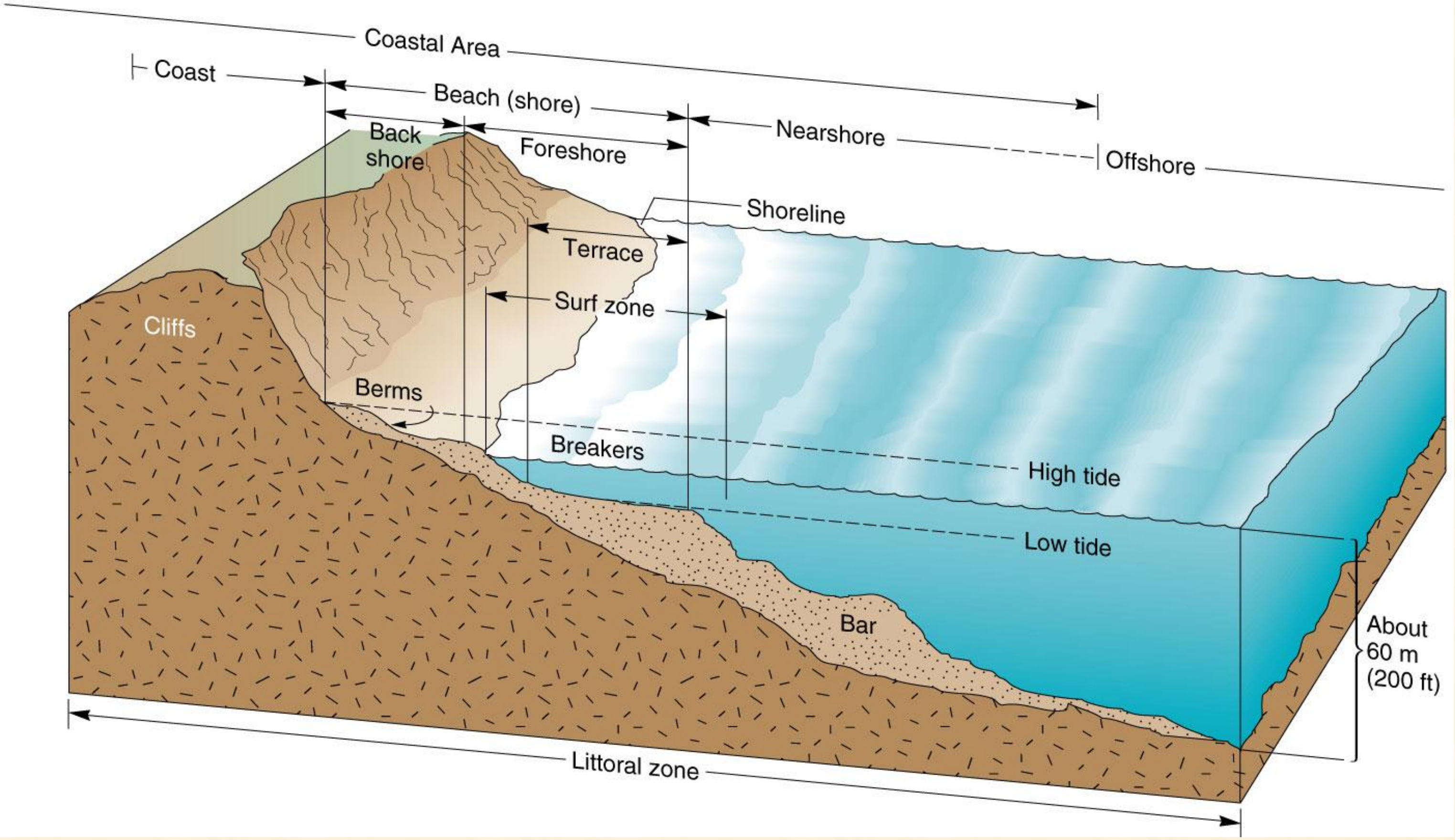


Coast: a strip of land of indefinite width that extends from the coastline inland as far as the first major change in topography.



- Cliffs, frontal dunes, or a line of permanent vegetation usually mark this inland boundary.

- On barrier coasts, the distinctive back-barrier lagoon/marsh/tidal creek complex is considered part of the coast.



The shore: extends from the low-water line to the normal landward limit of storm wave effects.

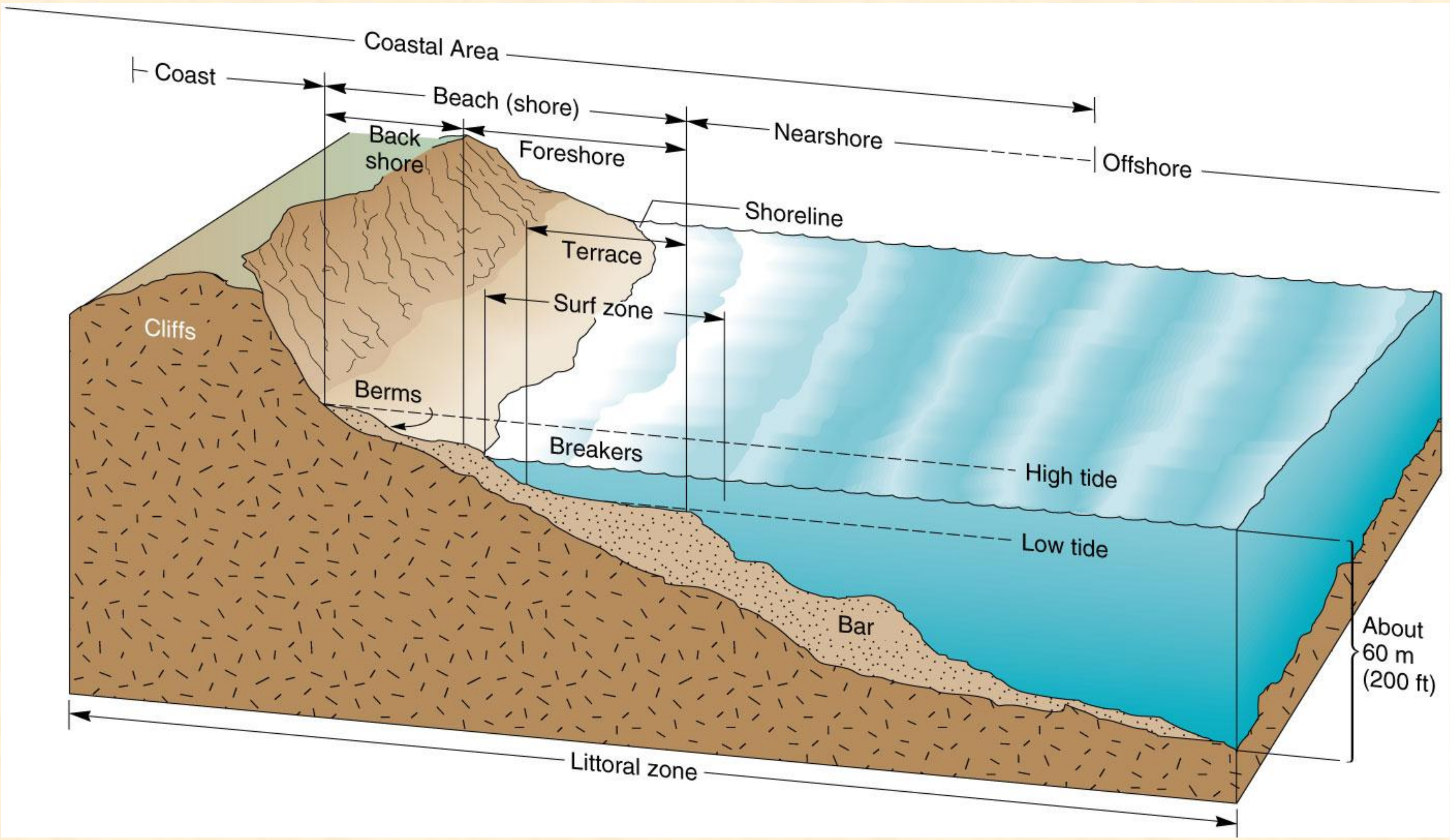
•divided into two zones: **backshore** (**berm**) and **foreshore** (**beach face**).

•**Foreshore**: low-water line to the limit of wave uprush at high tide.

•**Berm** crest: marks the juncture of the foreshore and backshore.

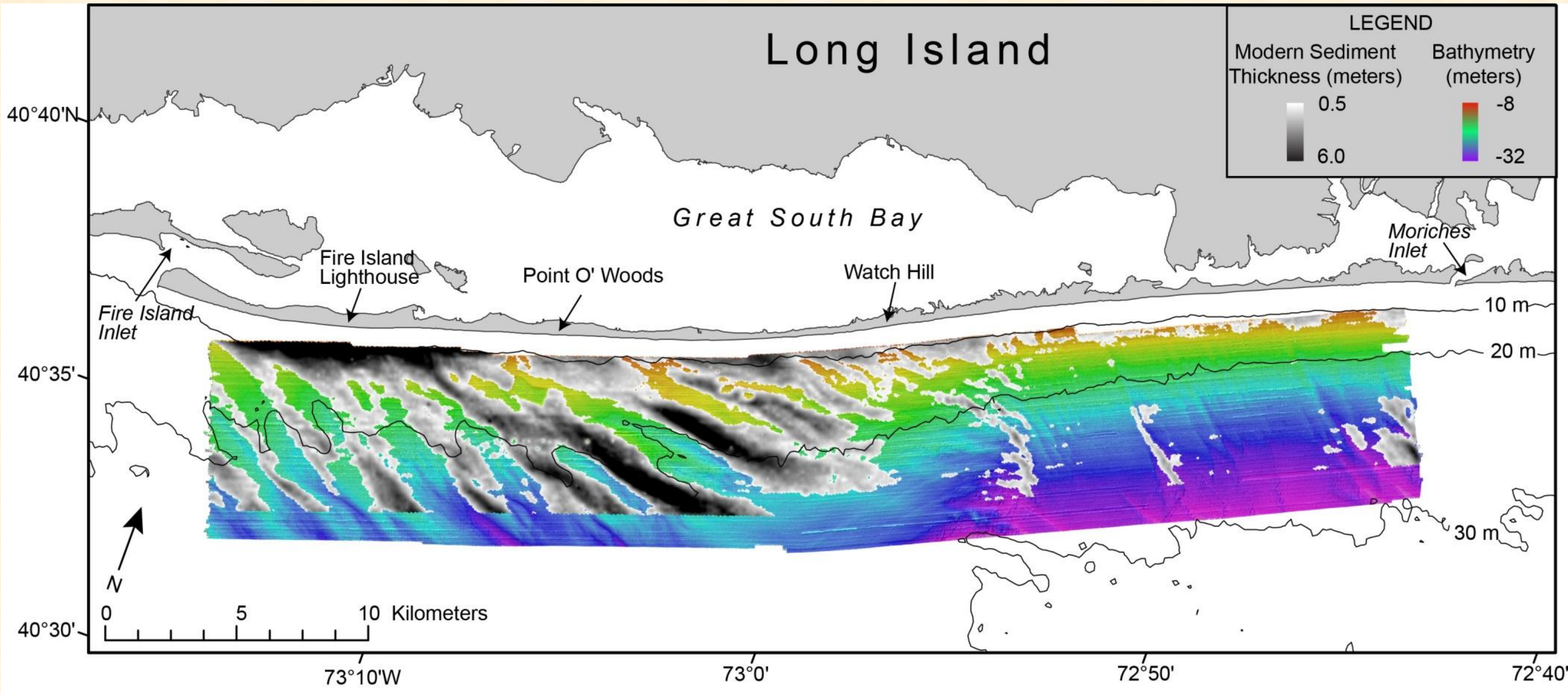
Shoreface: seaward-dipping zone that extends from the low-water line offshore to the beginning of the continental shelf (**slope transition, depth of no motion, end of the littoral zone**).

The shoreface is not found in all coastal zones



The shoreface can be delineated from shore perpendicular profile surveys or from bathymetric charts (if they contain sufficient soundings in shallow water).

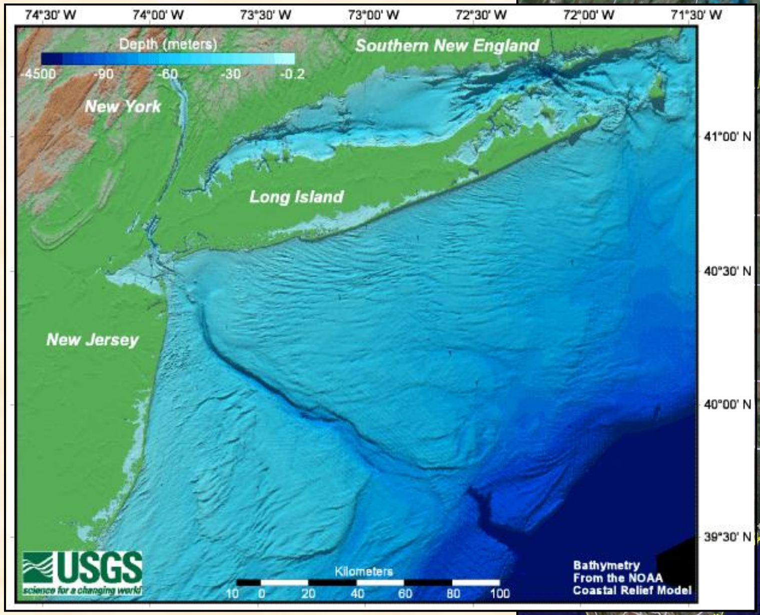
The shoreface is the zone of most frequent and vigorous sediment transport.



Continental shelf: the shallow seafloor that borders most continents.

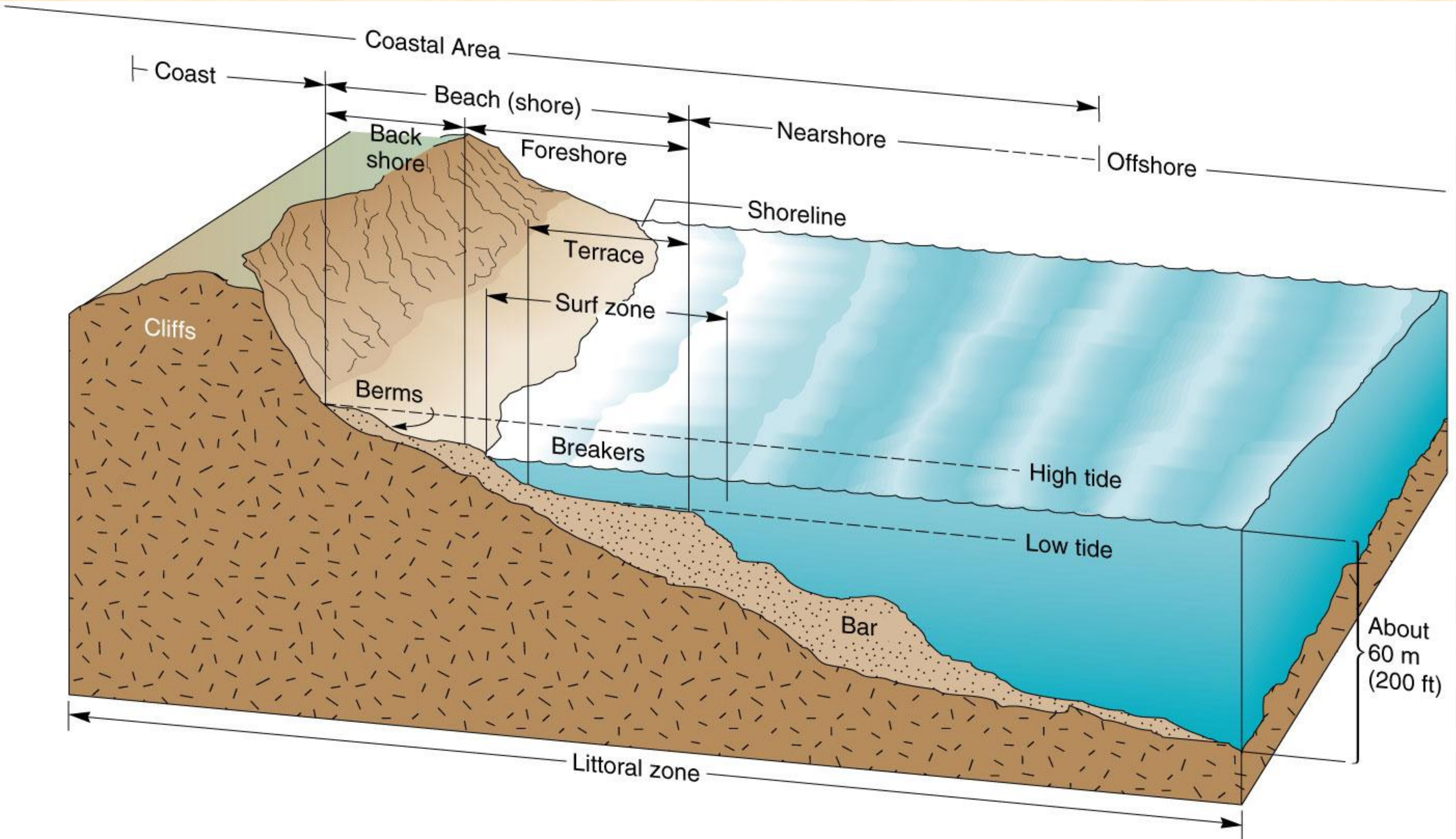
•Extends from the toe of the **shoreface** to the **shelf break** where the steeply inclined **continental slope** begins.

•It has been common practice to subdivide the shelf into inner-, mid-, and outer zones, although there are no regularly occurring geomorphic features on most shelves that suggest a basis for these subdivisions.



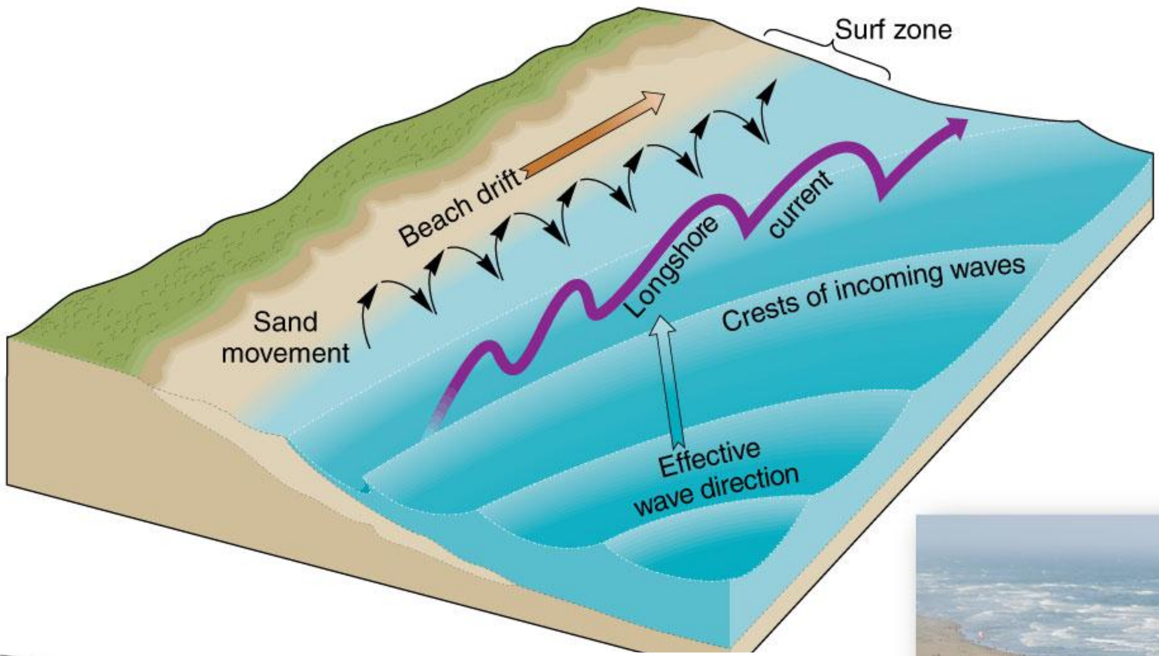
Littoral Zone

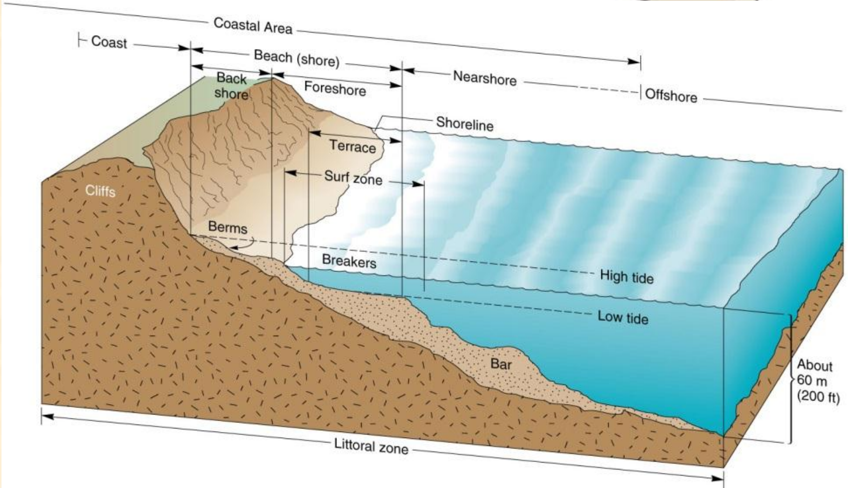
- The littoral zone extends inland to the highest water line during storms and seaward to the furthest area where wave processes stop influencing sediment transport and deposition on the seafloor (**shoreface, depth of no motion**).



Littoral Drift

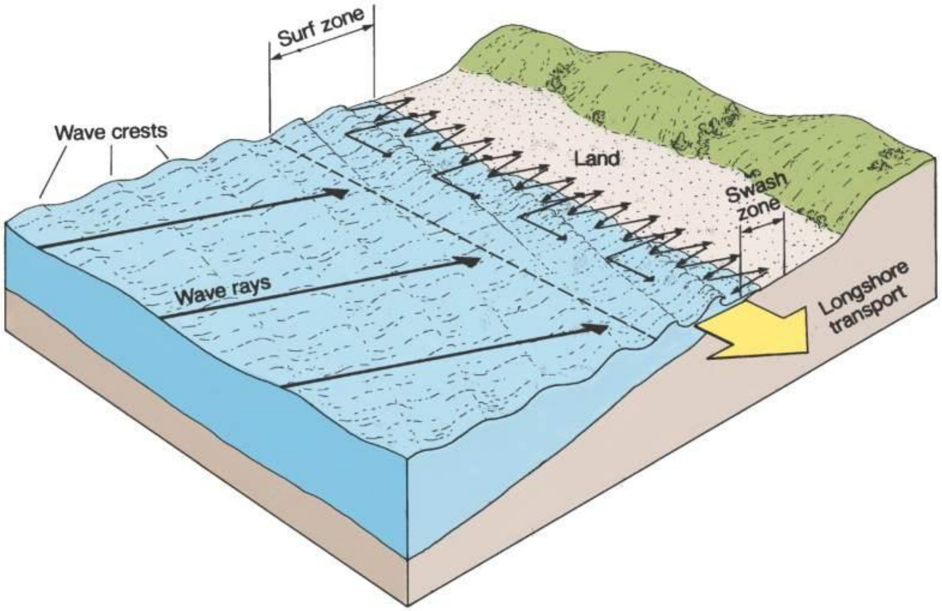
- all longshore transport within the littoral zone
- swash transport (beach drift), surfzone transport





(b)

Sediment Transport



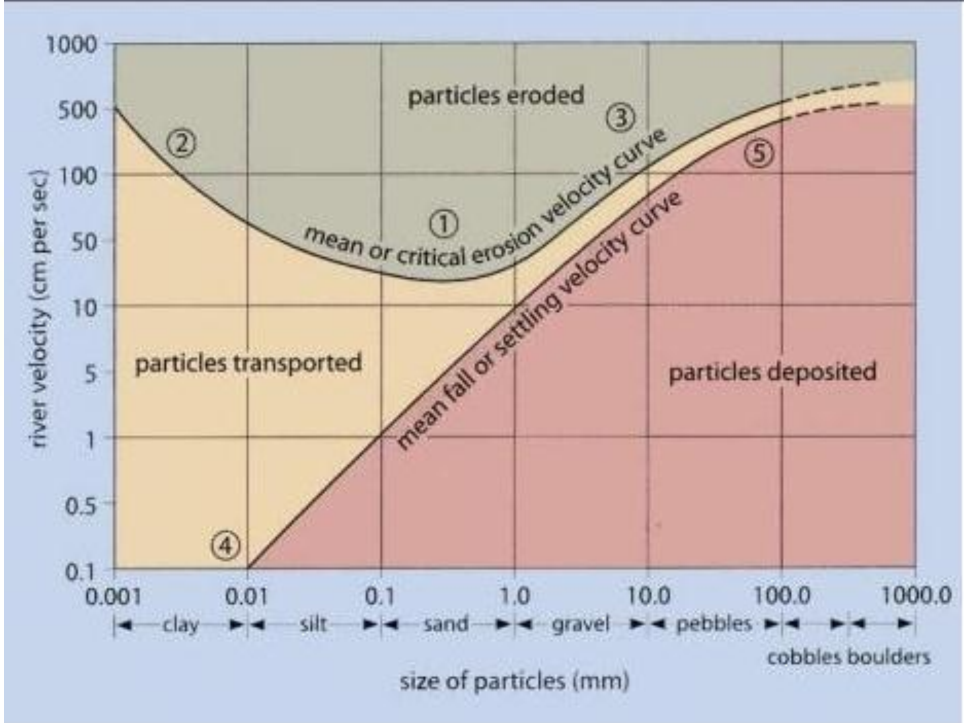


Table 3.1. Wave equations

	deep	*intermediate*	*shallow*	*near breaker*
phase velocity (C)	$\frac{gT}{2\pi}$	$\sqrt{\frac{gL}{2\pi}\tanh 2\pi\frac{h}{L}}$	$\sqrt{gh}$	$\sqrt{g(h+H)}$
wave length (L)	$\frac{gT^2}{2\pi}$	$L_o\sqrt{\tanh 2\pi\frac{h}{L_o}}$	$L_o\sqrt{\tanh 2\pi\frac{h}{L_o}}$	CT
wave height (H)	function	deep water	$\frac{H_o}{\sqrt[4]{\frac{8\pi h}{L}}}$	$0.32\, H_o\sqrt[3]{\frac{L_o}{H_o}}$
orbital diameter (d)	*surface* d= H_0 *bottom* $d_{bot} = 0$	$d_z = H\frac{\cosh\frac{2\pi z}{L}}{\sinh\frac{2\pi z}{L}}$	$d_z = \frac{HL}{2\pi h}$	$d_z \cong \frac{3H}{2}$
maximum orbital velocity (u_m)	$\frac{\pi d}{T}$	$\frac{\pi d}{T}$	$\frac{HC}{2h}$	$u_{m,o} \cong \frac{HC}{3h}$
limits of application	$\frac{h}{L_o} > \frac{1}{4}$	$\frac{h}{L_o}$ *from* $\frac{1}{4}$ *to* $\frac{1}{20}$		$\frac{H}{h} > \frac{1}{4}$

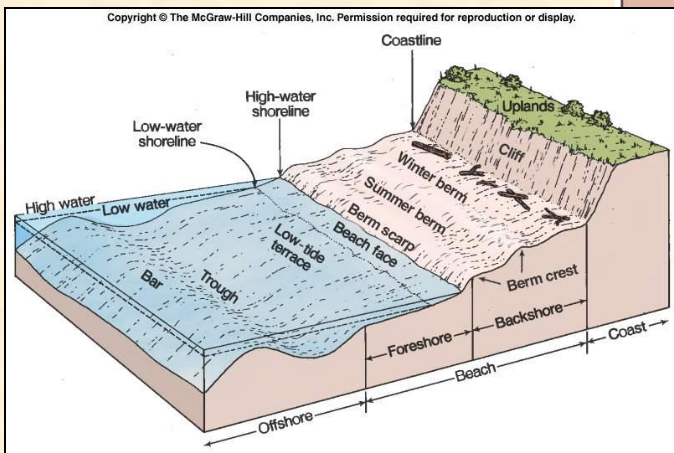
Beaches

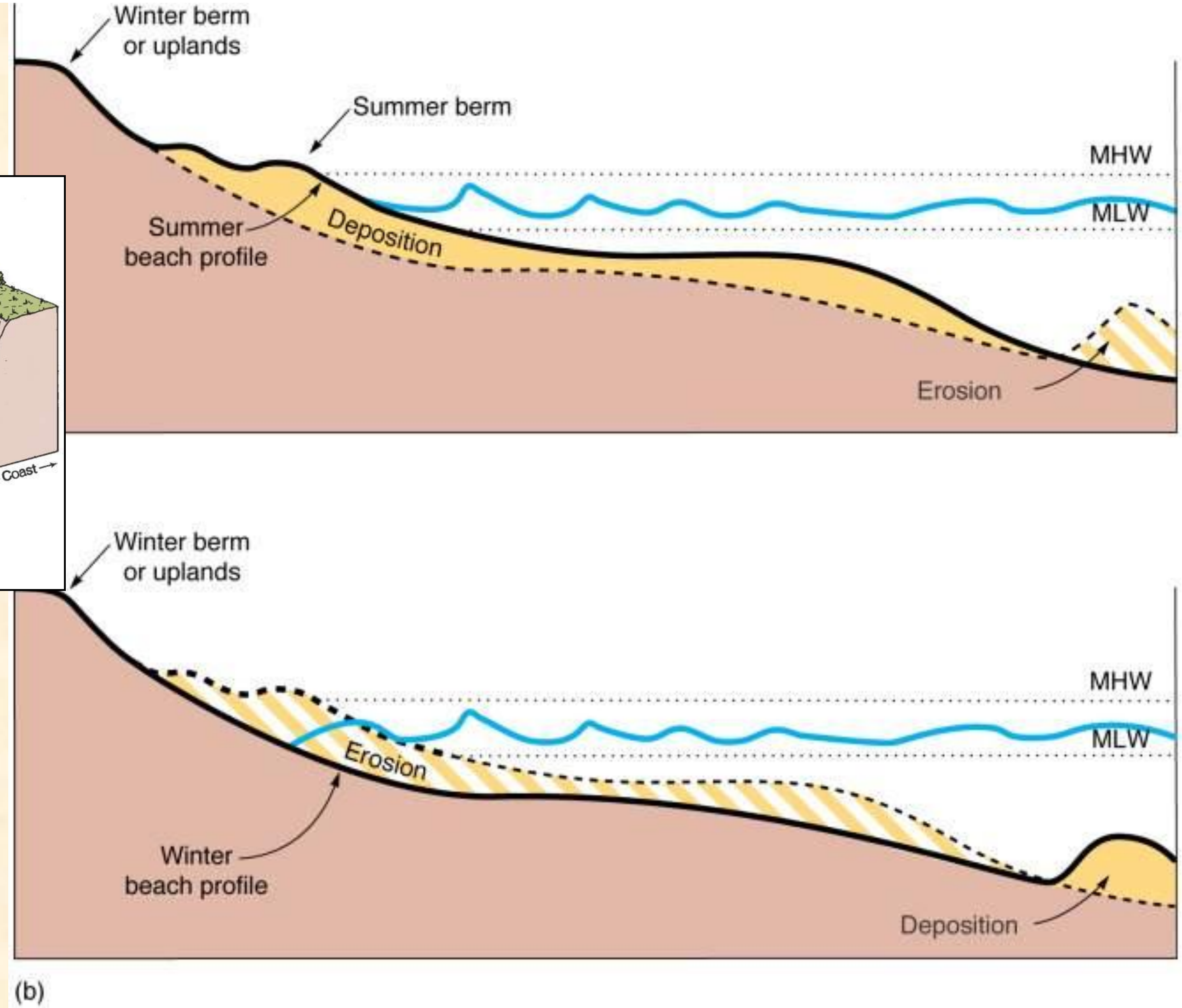
- Depositional landforms.
- Most often associated with sand-sized quartz grains, shells or shell hash.
- Dependent on source of material (volcanic, coral, gravel etc.)
- Seasonal/storm cycles of evolution, accretion: wider higher during calm summer months, deflation: narrow, low profile during storm season.
- Stable, Erosional, Acretional

Beach Dynamics:

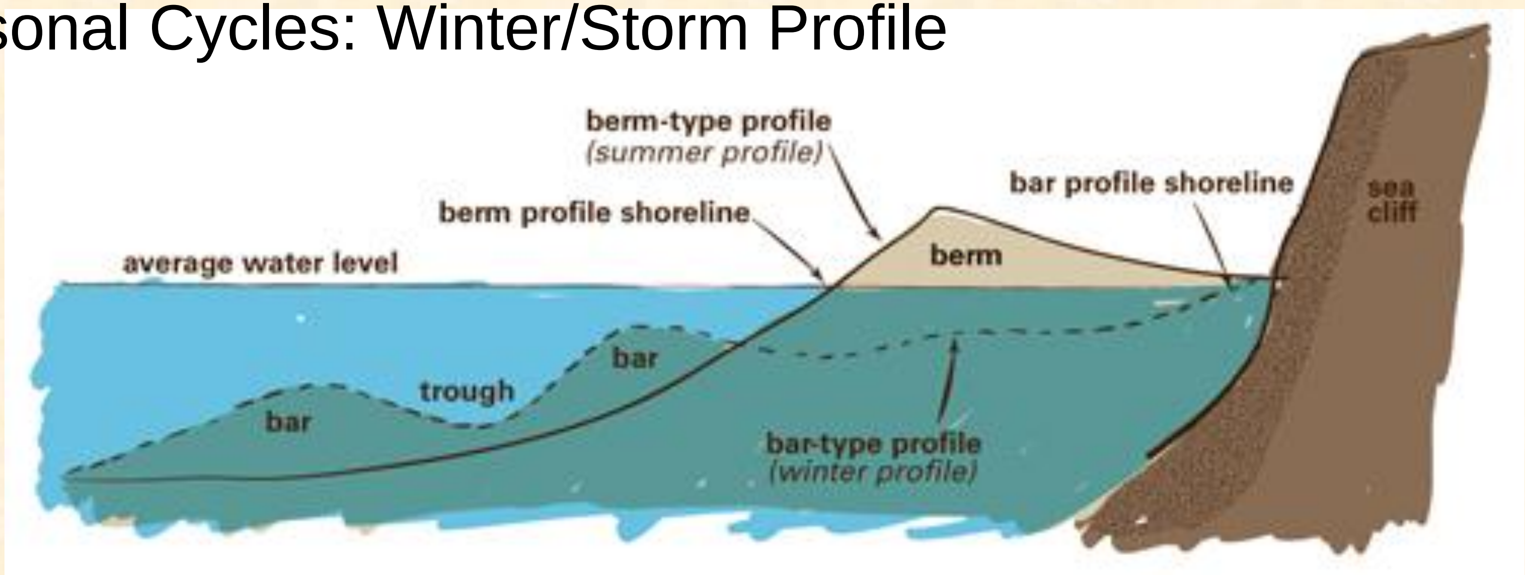
Summer: gentler waves move sand shoreward

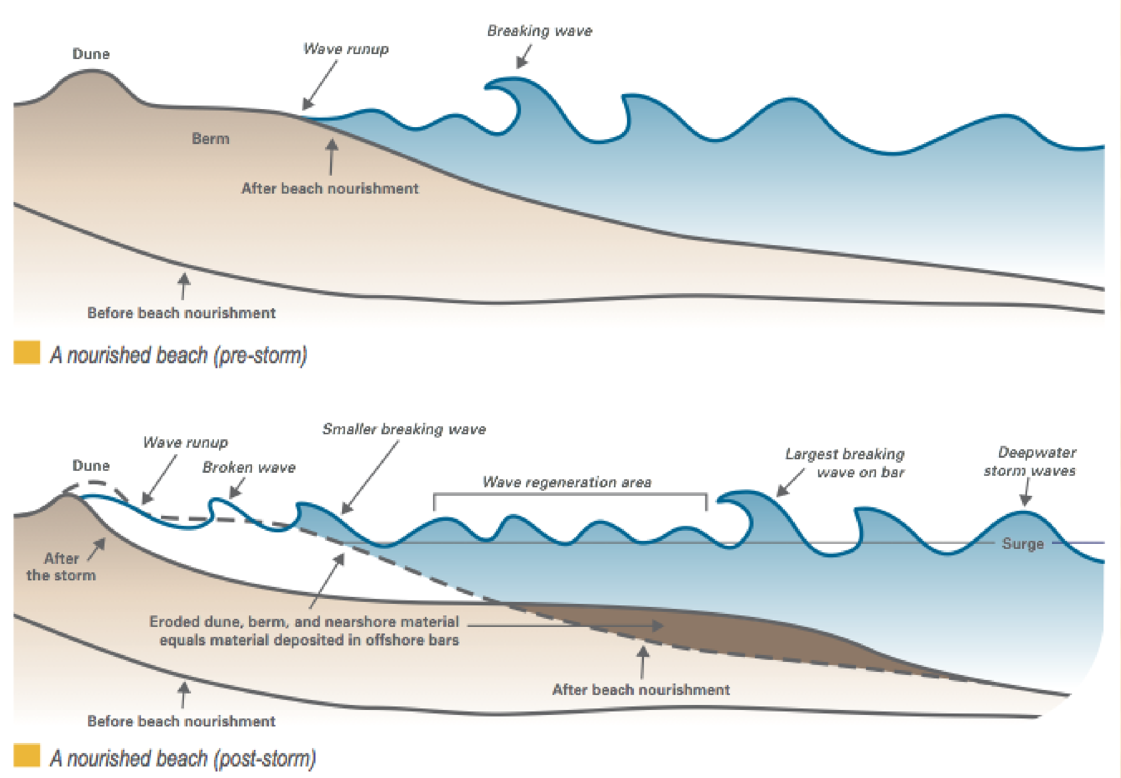
Winter: large storm waves remove sand to offshore bars



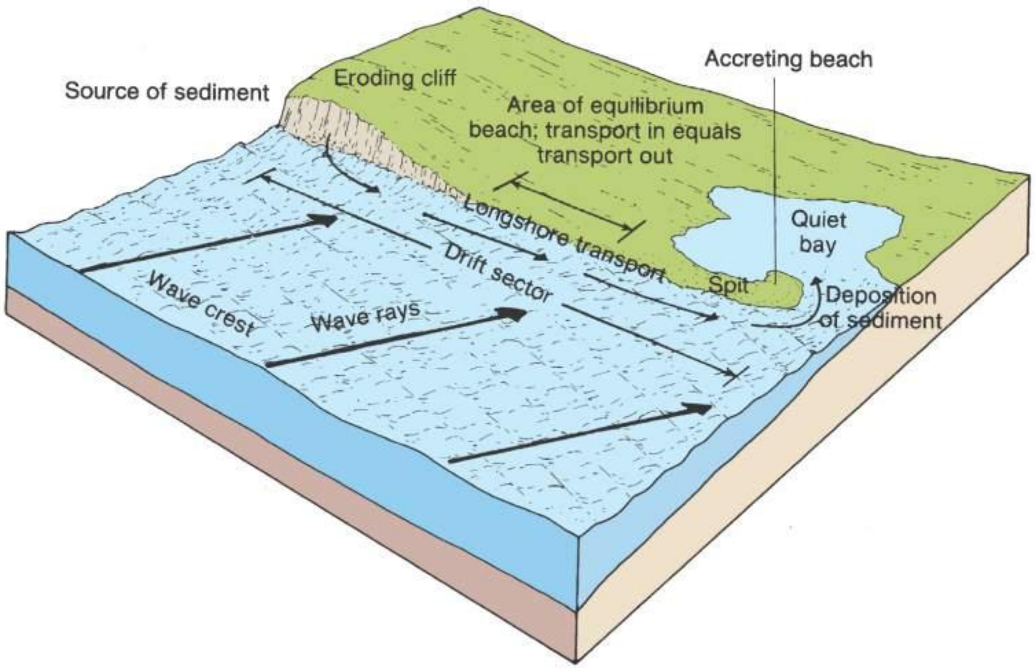


Seasonal Cycles: Winter/Storm Profile

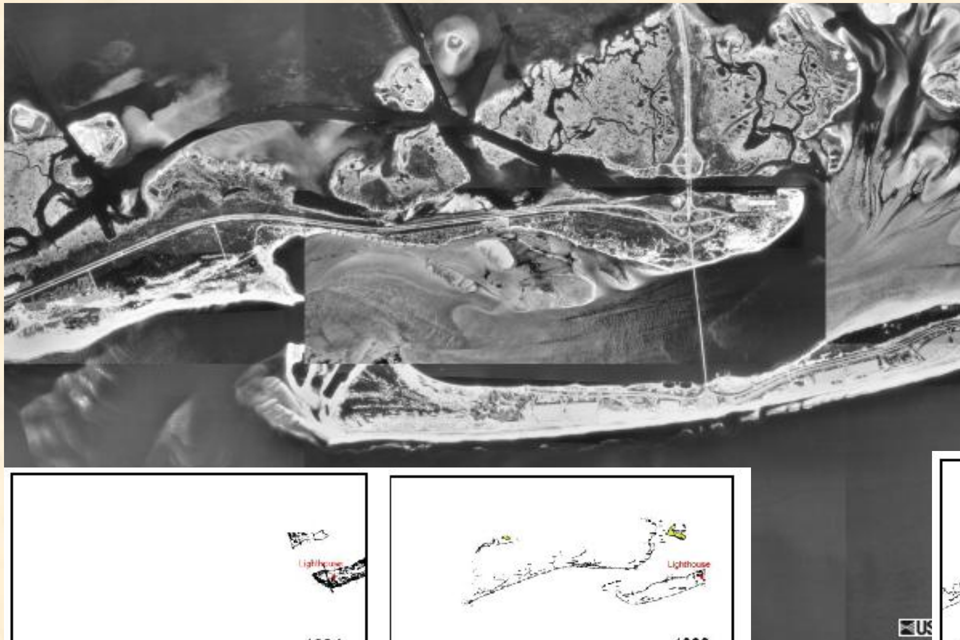


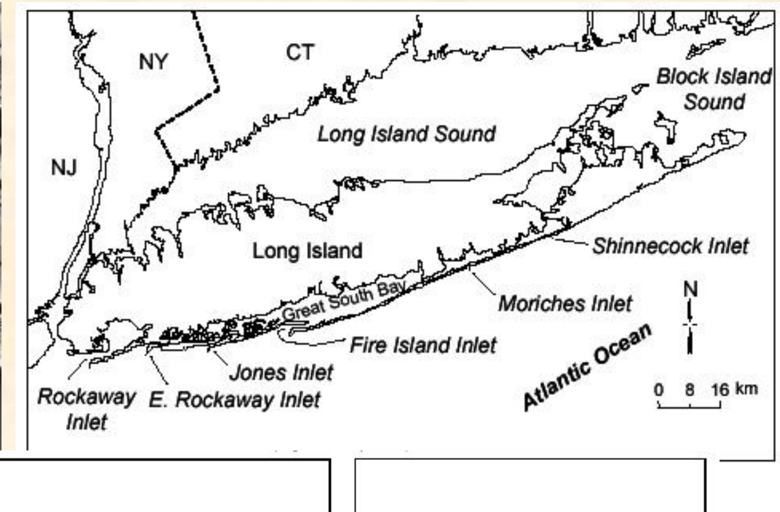


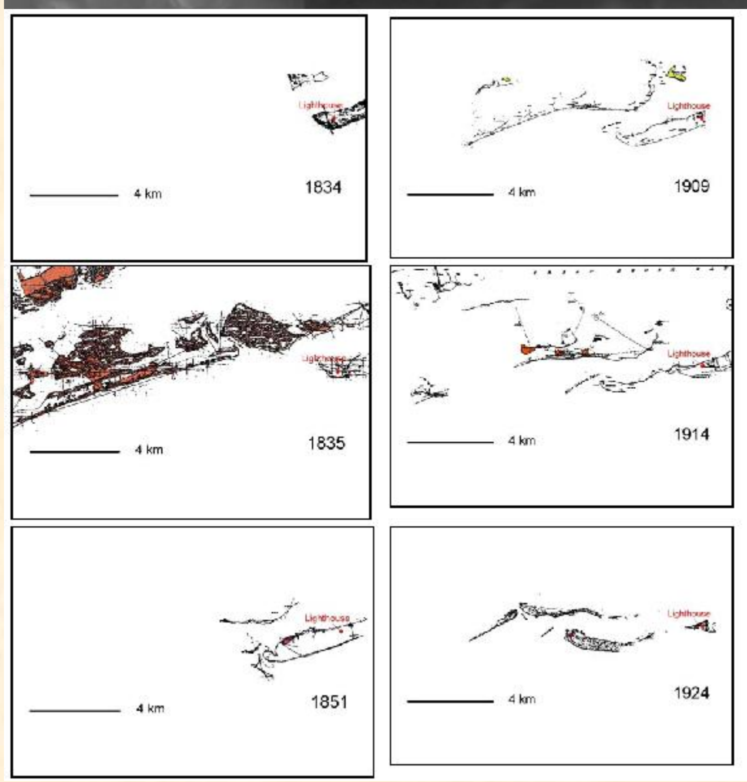
Barrier and Spit Formation

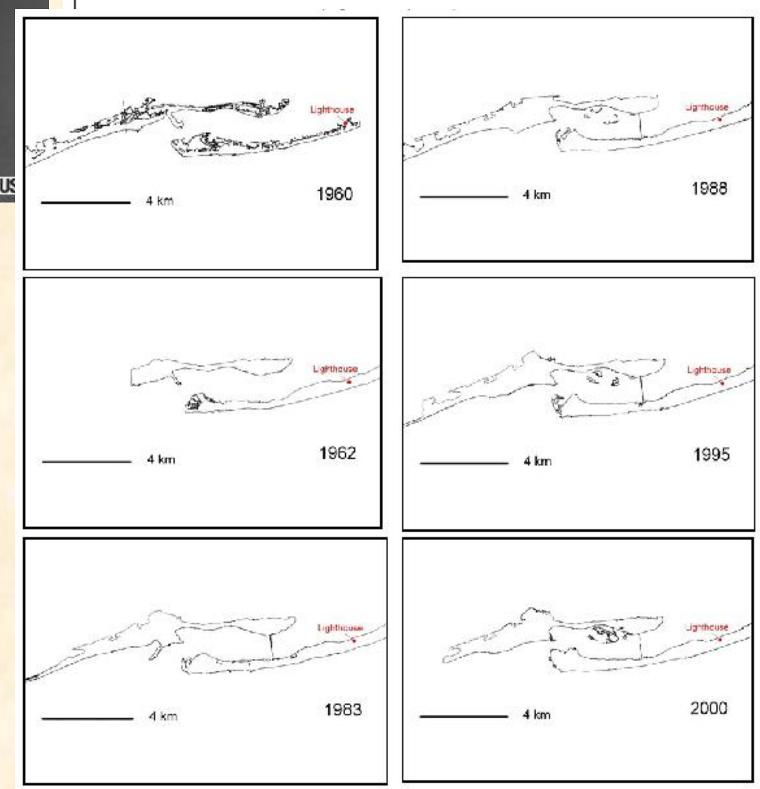


Spit Building Fire Island Inlet



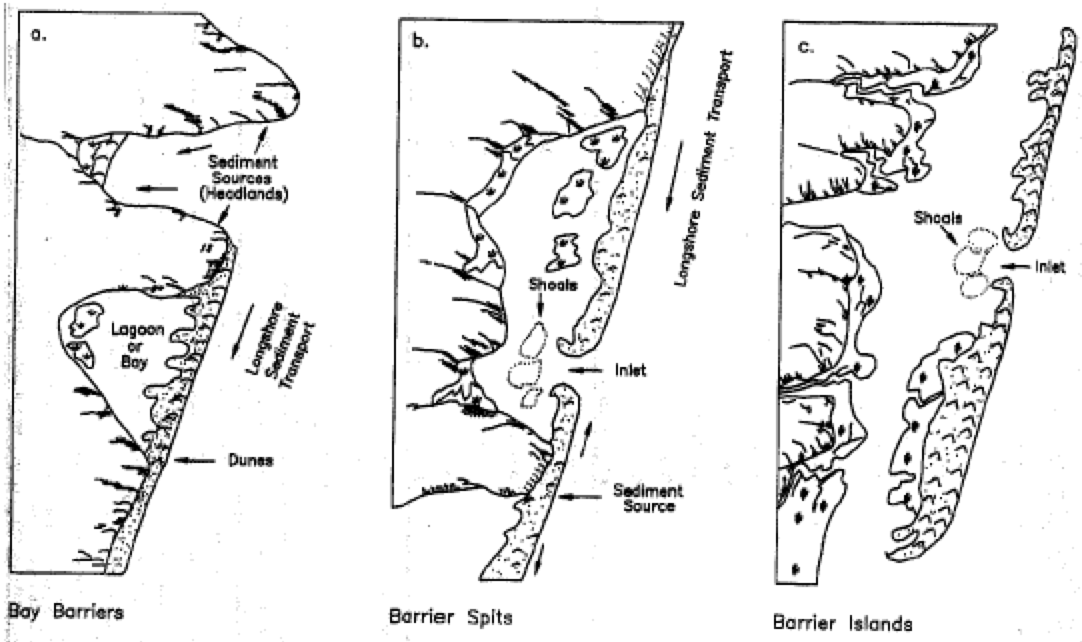






Marine Deposition Coasts: Barrier Coasts

Three classes of barrier structures:
- Bay barriers
- Spits
- Barrier Islands



Models for origin and evolution:

Barrier sediments initially deposited as river deltas

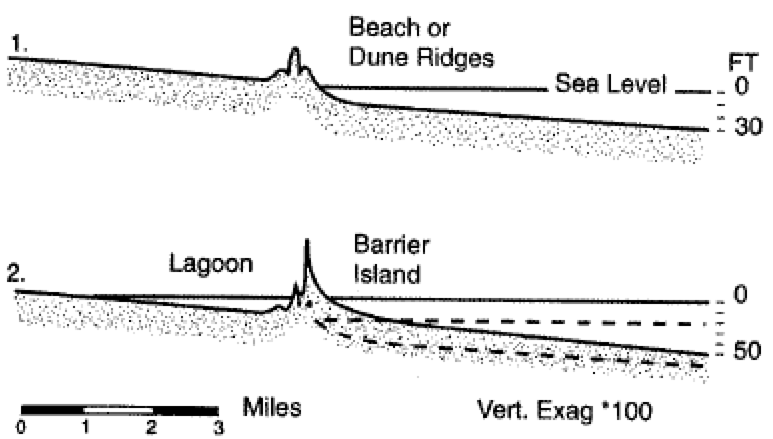
Various theories:

Emergence
- Form offshore as sand bars

Submergence
- Form from mainland beach / dune complex

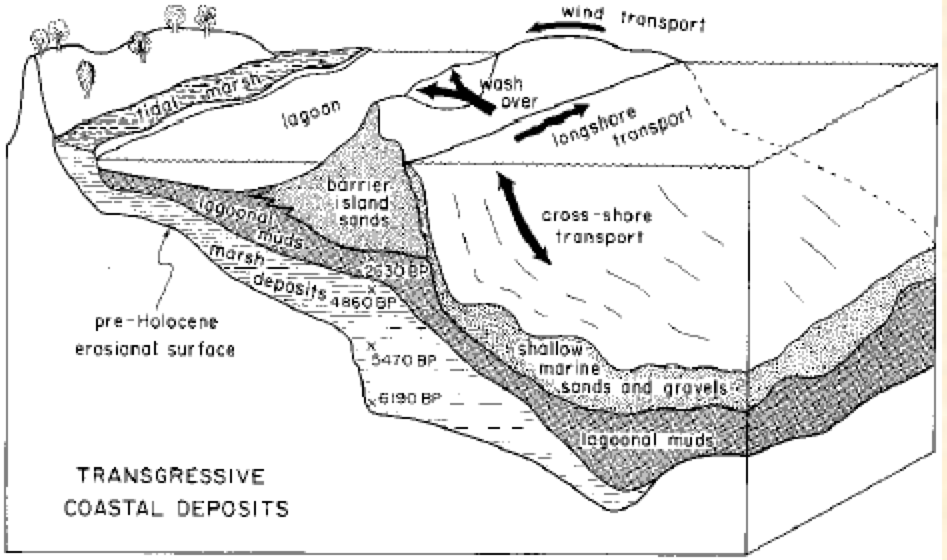
Spit detachment
- Form from coastal erosion, longshore transport

Combined origin

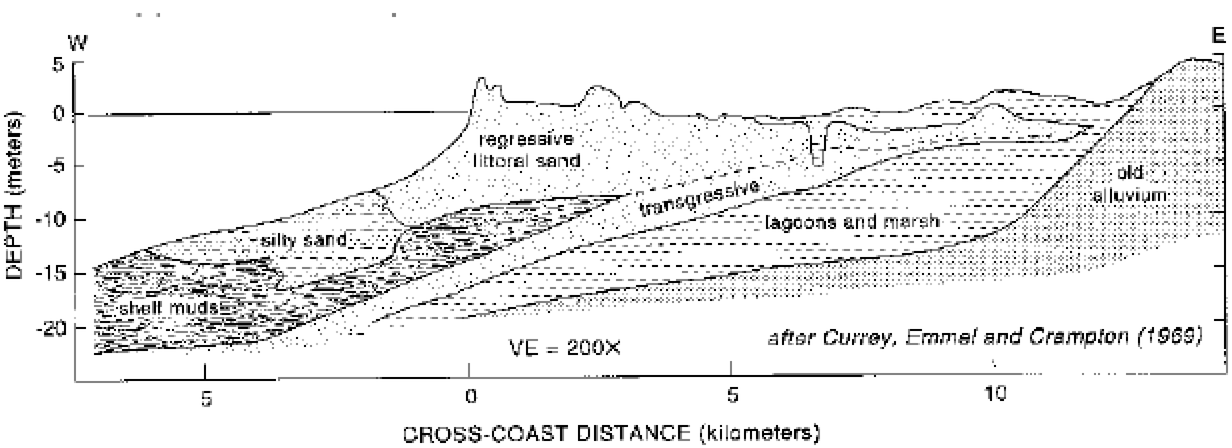


Marine Deposition Coasts: Barrier Coasts

Migrate w/ variations in sea level
- Rising sea level / low sediment supply:
  - landward migration (transgression)
- Falling sea level / high sediment supply:
  - seaward migration (regression)

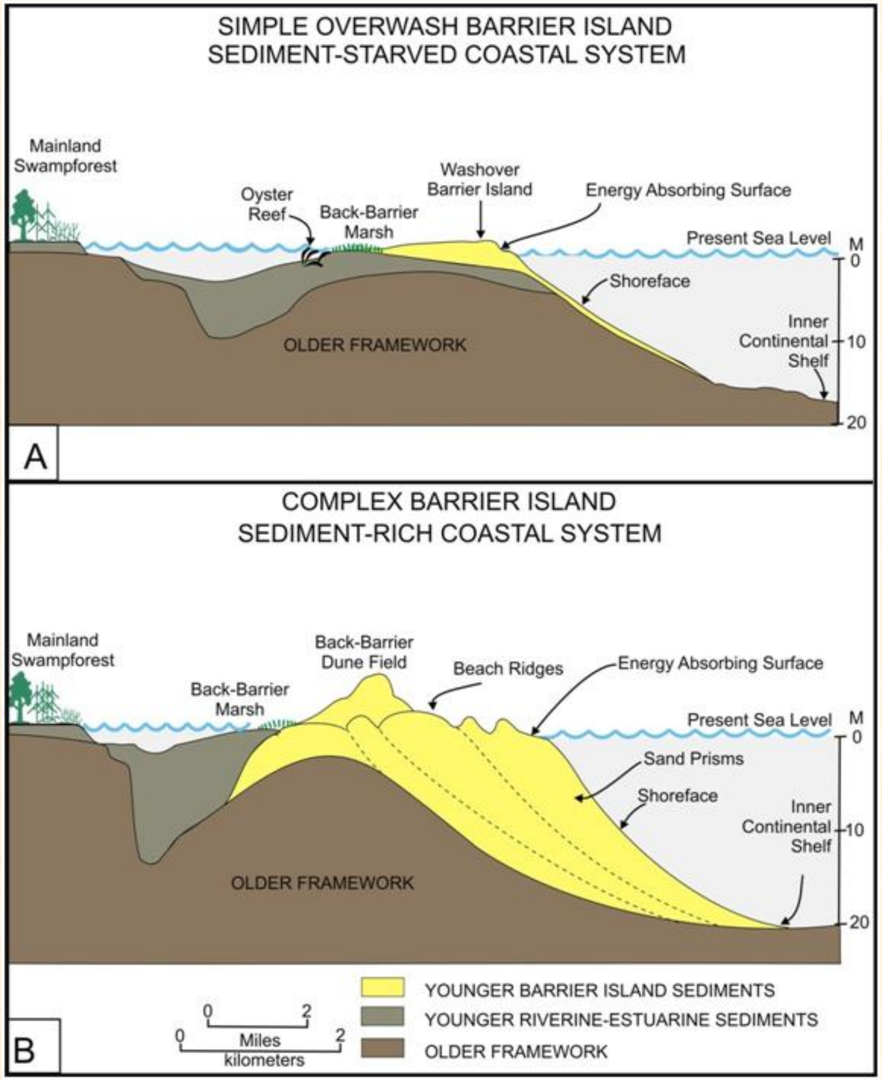


Transport mechanisms:
- Wind (Eolian)
- Overwash
- Flood tide deltas



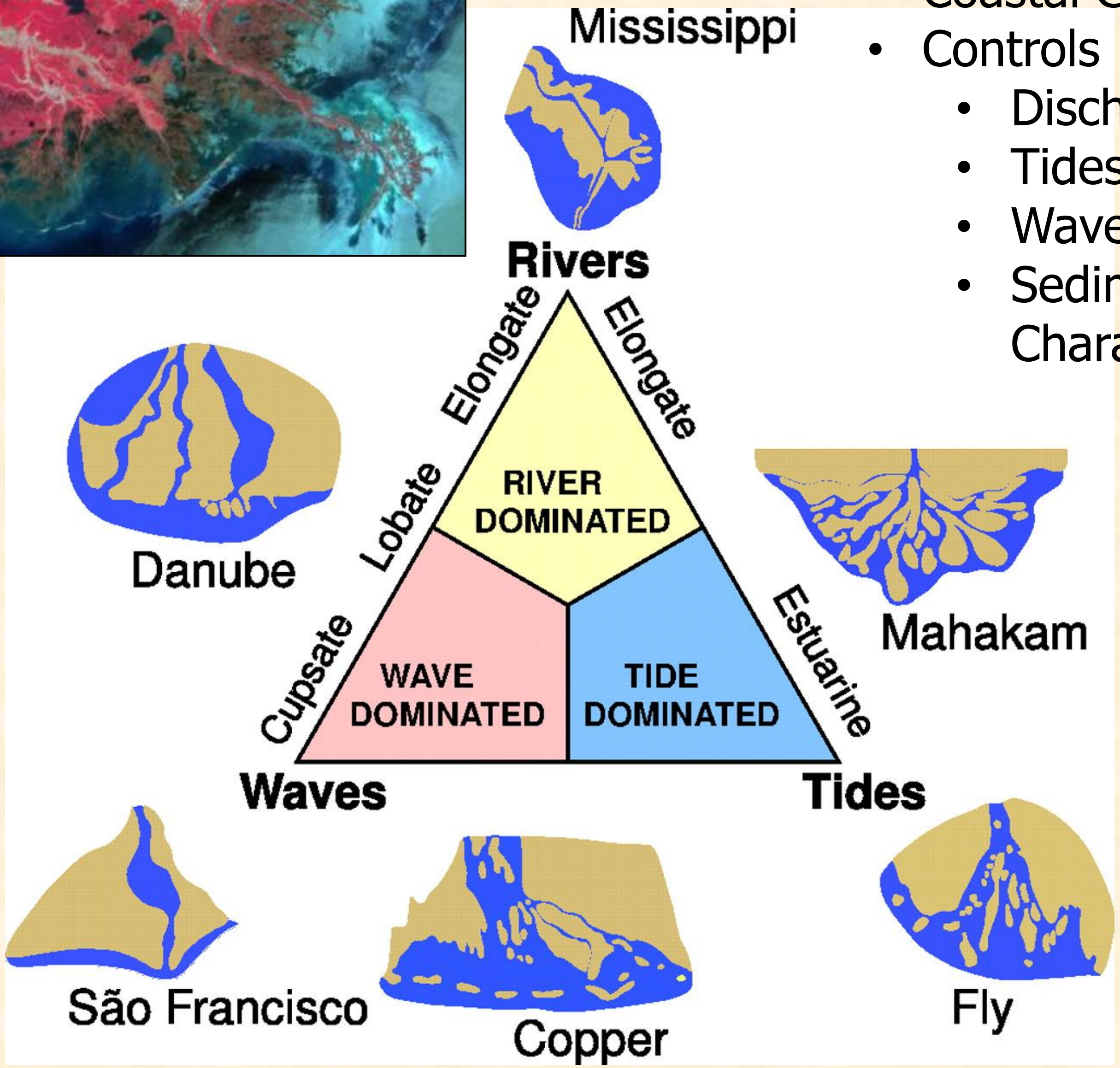
Beach Ridges

- Beach ridges are wave-deposited ridges that form parallel to the coastline. They are composed of gravel, sands, and shell fragments, and in some cases they may be capped by aeolian sands blown from the beach.

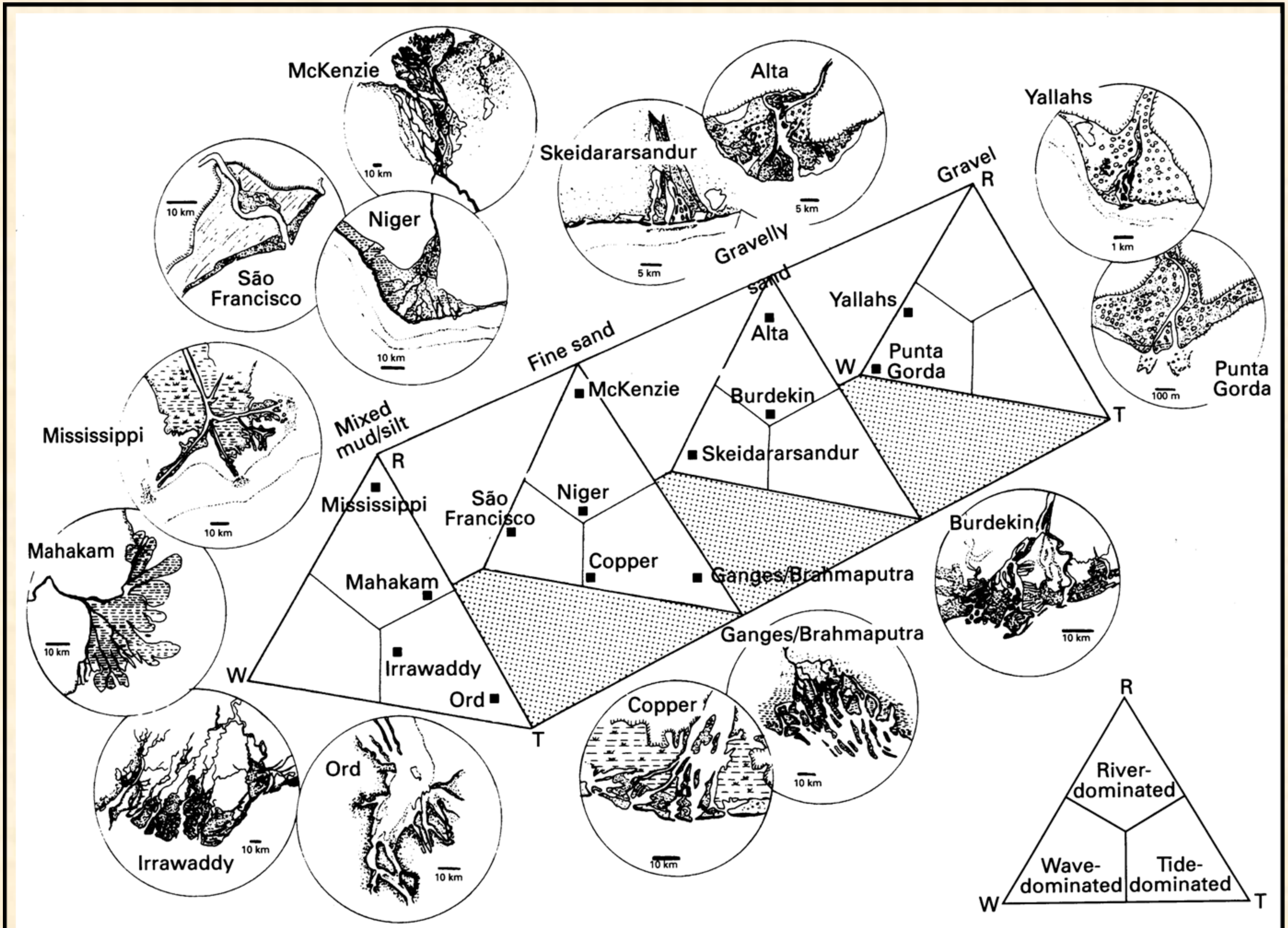


Deltas

- Coastal Geomorph
- Controls
  - Discharge
  - Tides
  - Waves
  - Sediment Characteristics



Deltas



McKenzie
10 km
Alta
5 km
Skeidararsandur
5 km
Yallahs
1 km
10 km
São
Francisco
Niger
10 km
Gravelly
Gravel
R
Yallahs
Punta
Gorda
100 m
Punta
Gorda
Mississippi
10 km
Fine sand
sand
Alta
W
McKenzie
Burdekin
T
Mixed
mud/silt
Skeidararsandur
R
Mississippi
São
Francisco
Niger
Burdekin
10 km
Mahakam
Copper
Ganges/Brahmaputra
Mahakam
10 km
Ganges/Brahmaputra
Irrawaddy
W
Ord
T
Copper
10 km
Ord
10 km
Irrawaddy
10 km
10 km
R
River-
dominated
Wave-
dominated
Tide-
dominated
W
T

Sea Cliffs

Sea cliff formation:

Primary:

- Volcanic eruptions / uplift from local volcanism
- Diastrophic activity resulting in vertical motion of sections of coast
- Shoreline erosion at drowned steep terrain

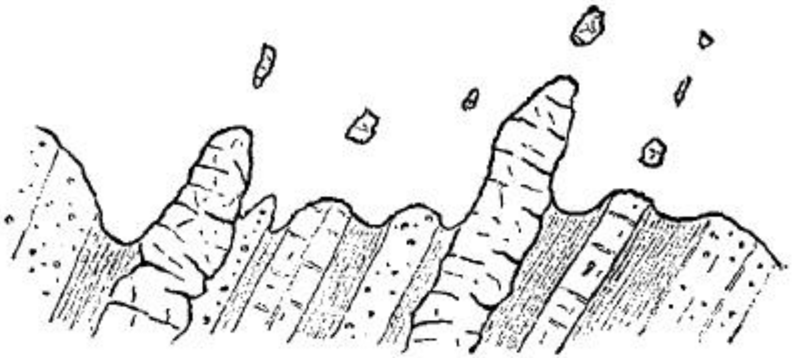
Erosional coasts

- Straight or irregular
→ depending on rock type and wave climate

Irregular:

wave erosion

Rock, sediment layers *parallel* or at angle to coastline



other erosional forces: chemical, biological

Secondary Coasts:
Sea Cliffs (Erosional)

Wave straightened coasts: Exposed bedrock, steep slopes, deep water

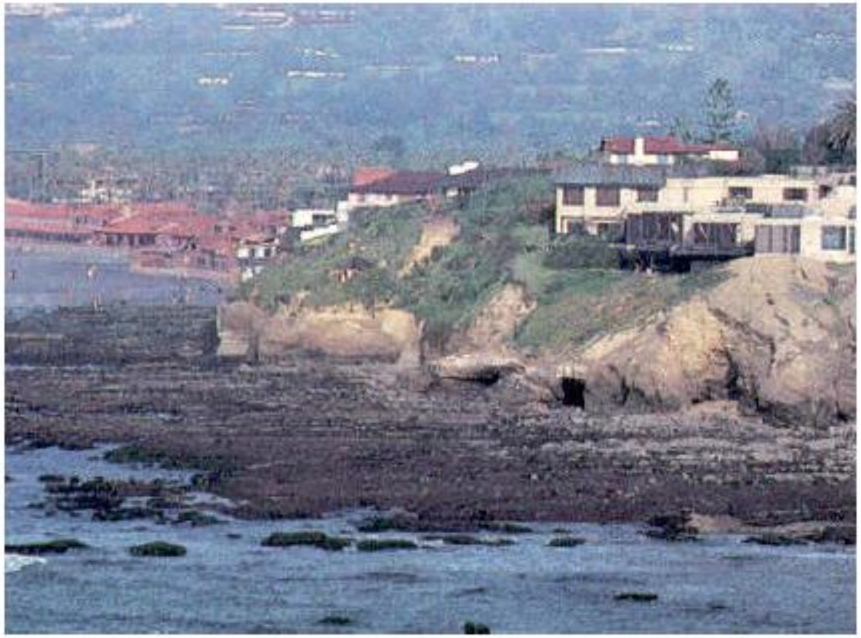
Rock layers parallel to coast – uplift/folding/faulting

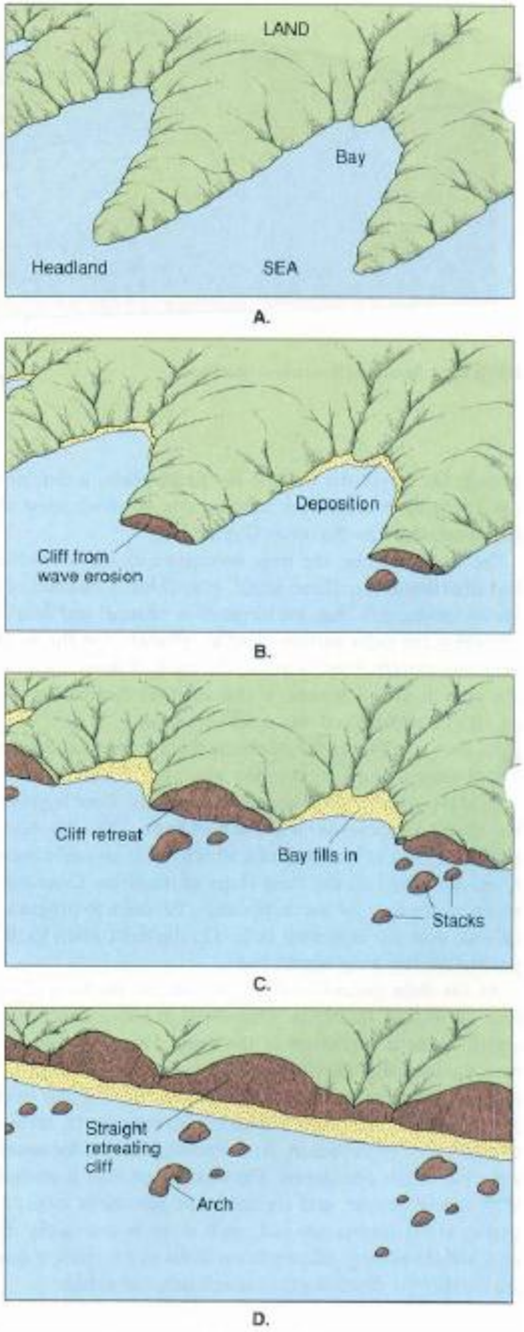
Beach at cliff base

may armor a shore

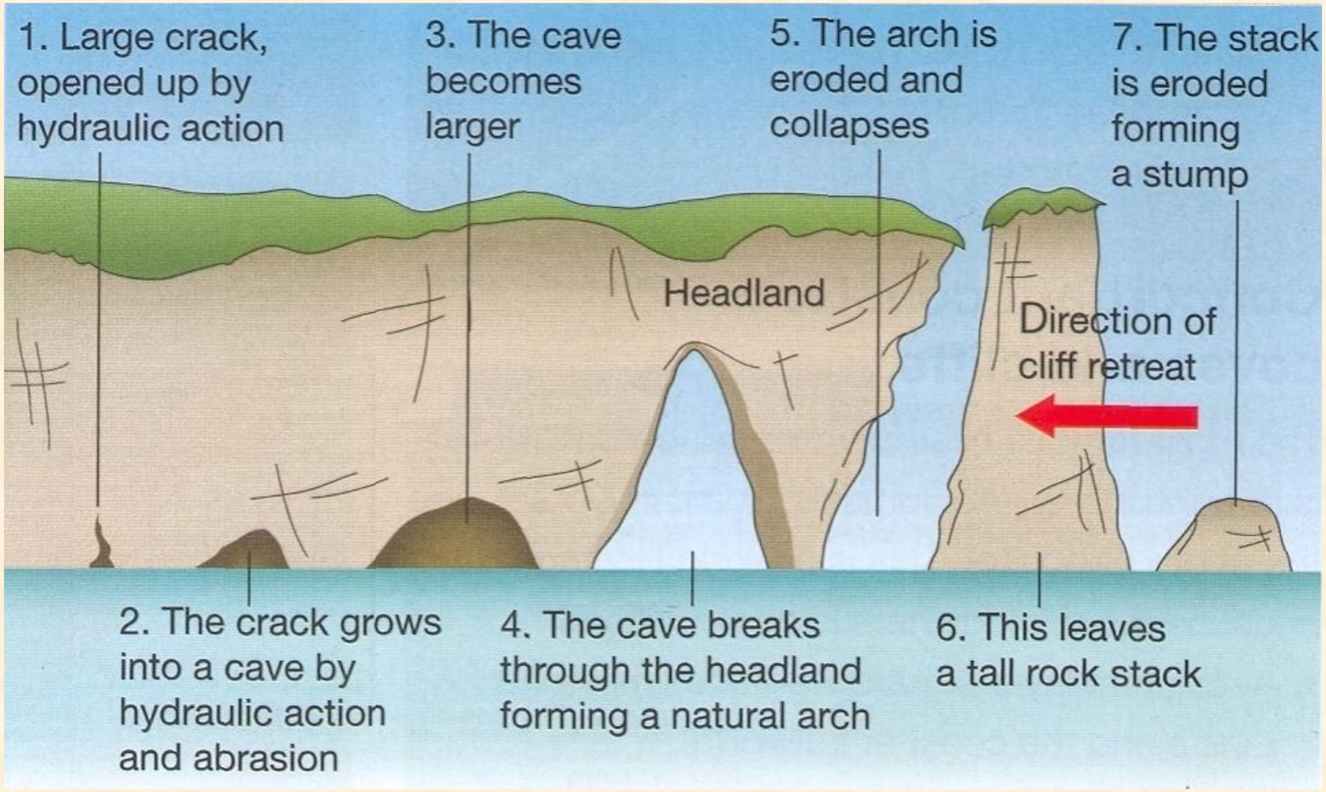
sand → 'blasting' agent for erosion

Wave cut platform:

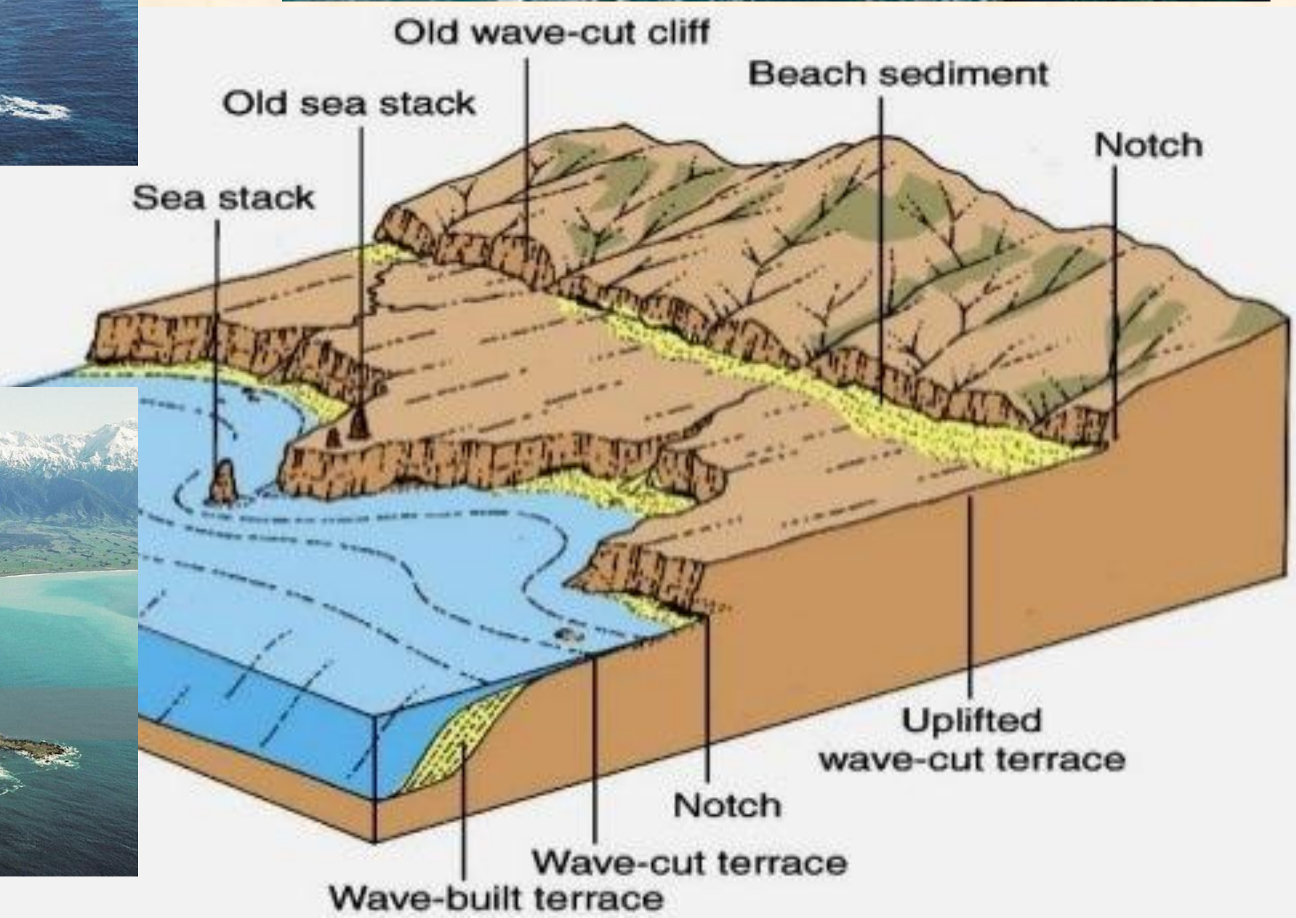




Differential Erosion: Sea Arch, Stacks



Marine Terraces

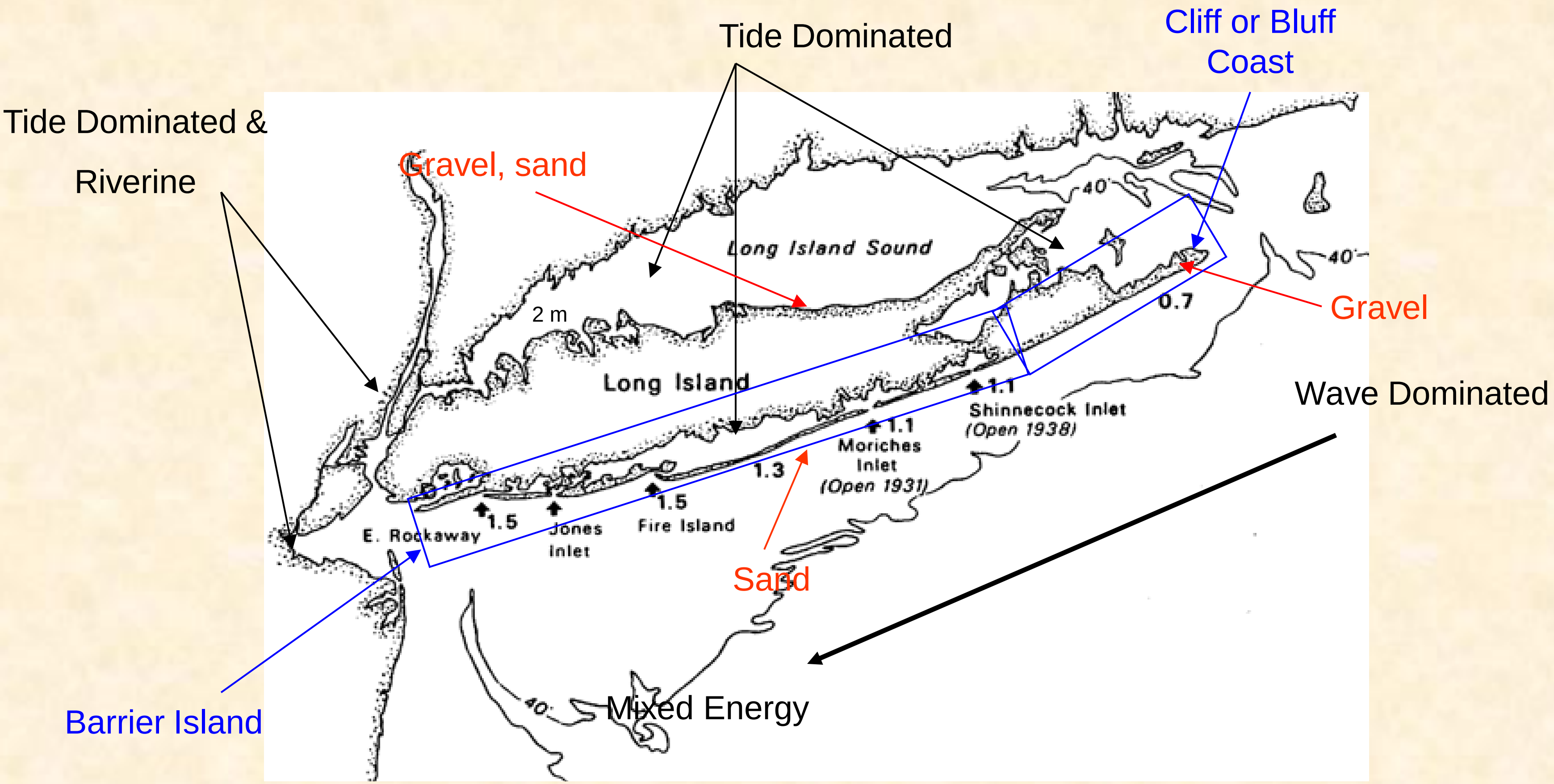


Coastal Diversity: Long Island

Amero-Trailing Edge Coast

South Shore Significant Wave Conditions: H ~= 1.5 m, T = 8 sec

Micro-Meso Tidal Environments



Atlantic North: Glaciated Coast

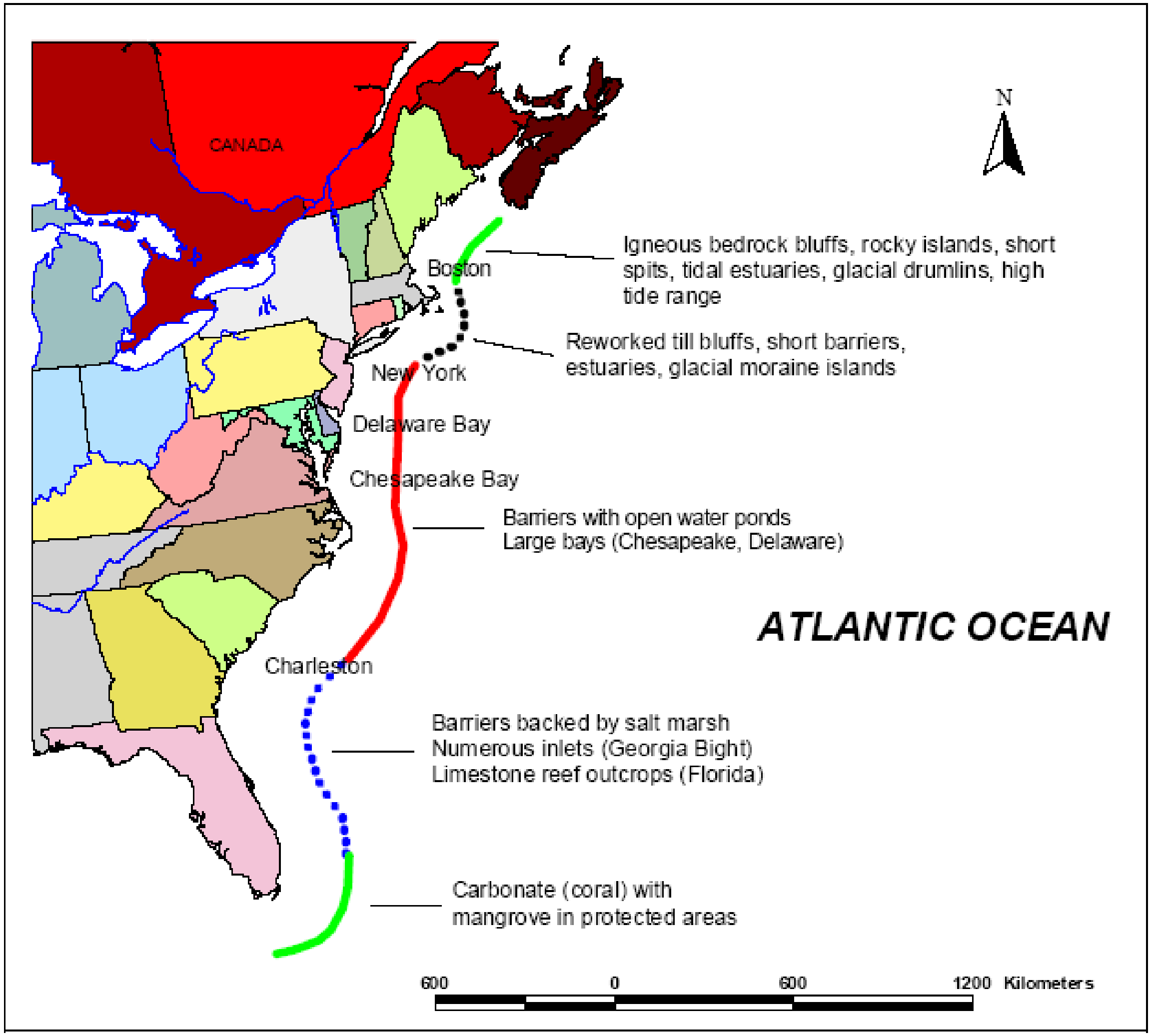


Figure I-2-1. Atlantic coast characteristics

- Coasts are deeply indented and bordered by numerous rocky islands.
- The embayments usually have straight sides and deep water as a result of erosion by the glaciers.
- Uplifted terraces as a result of isostatic rebound.
- Moraines, drumlins, and sand dunes, the result of reworking outwash deposits, are common features.
- Glaciated coasts in North America extend from the New York City area north to the Canadian Arctic, on the west coast, from Seattle, Washington, north to the Aleutian Islands, and in the Great Lakes. (Shepard 1982).

Atlantic Central & South: Barrier and Drowned Valley Coasts

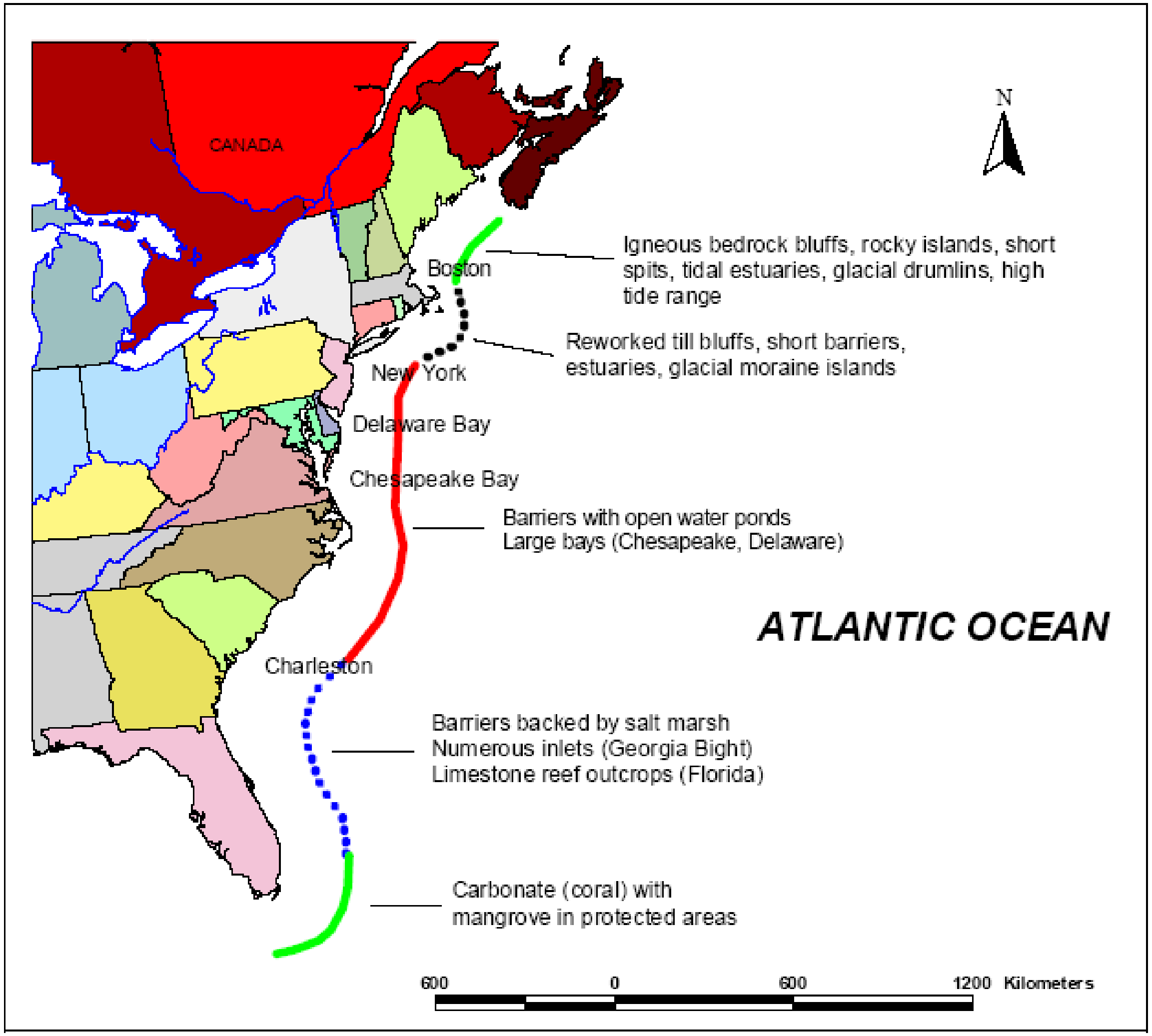


Figure I-2-1. Atlantic coast characteristics

- The Atlantic coastal plain, features almost continuous barriers interrupted by inlets and by large embayments with dendritic drowned river valleys, the largest being Delaware and Chesapeake Bays.
- Extensive wetlands and marshes mark much of the coast, where sediment and marsh vegetation have partly filled the lagoons behind the barriers.
- The best exhibit of cuspate forelands in the world extends from the mouth of Chesapeake Bay to Cape Romain, South Carolina.
- Extensive development along the southeast coast of Florida.
- From Miami through eastern Louisiana, coastal characteristics alternate between swampy coast and white sand barriers.

North American has over 10,000 km of barriers, 1/3 of all barrier coast of the world.

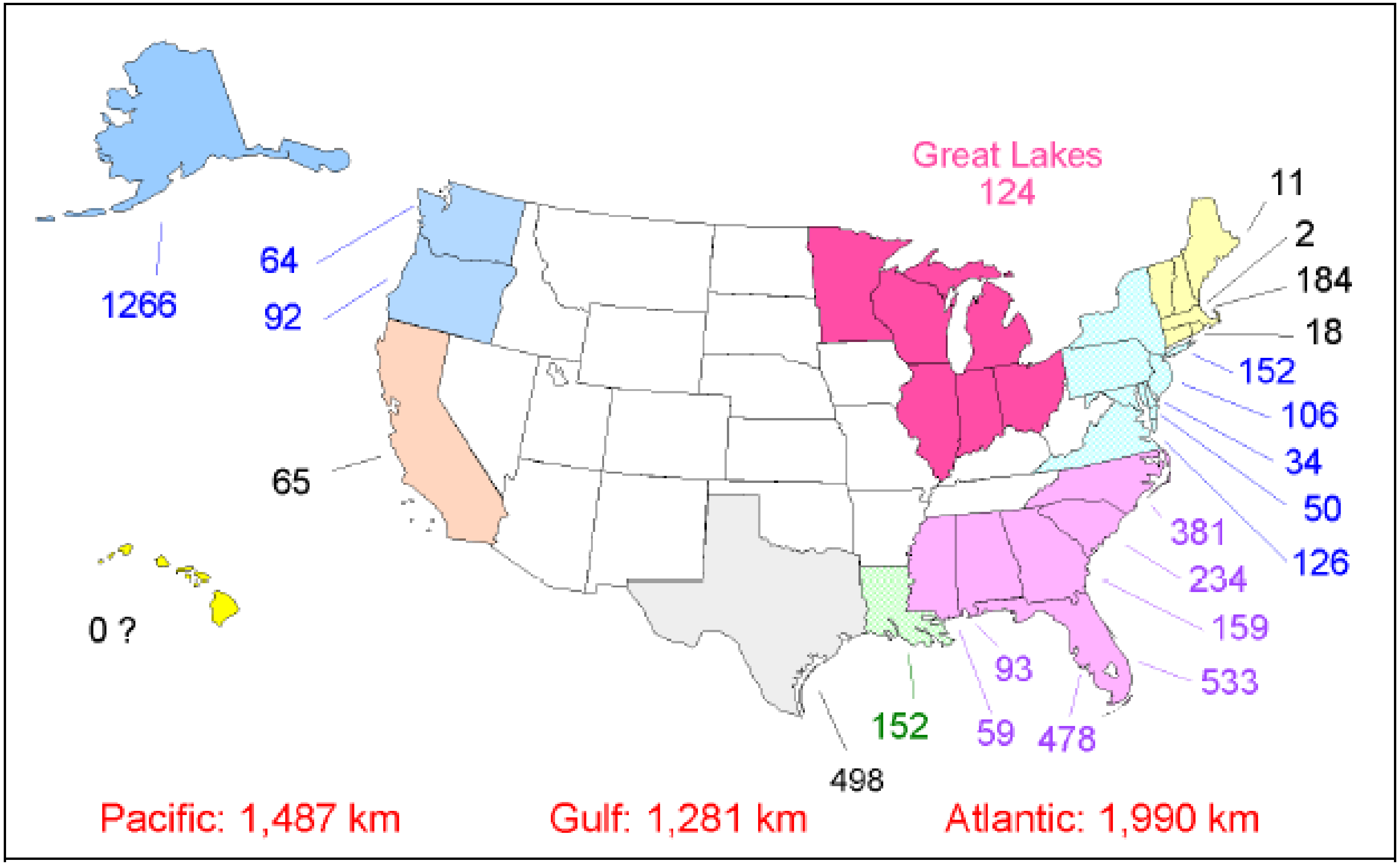


Figure I-2-5. Length (in km) of barrier islands and spits in the United States. Data measured from U.S. Geological Survey topographic maps (see Table IV-2-3 for details)

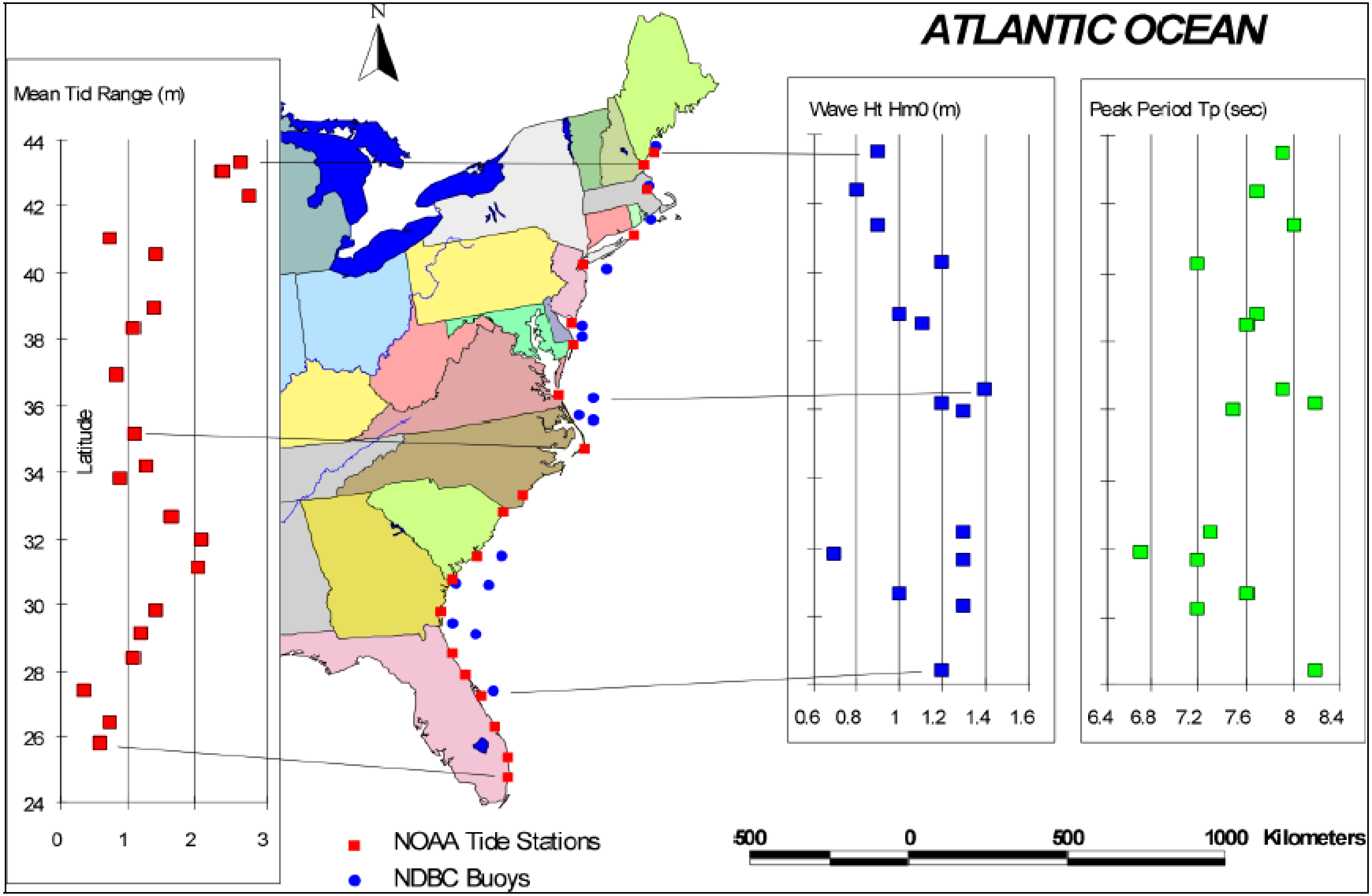


Figure I-2-2. Tide and wave characteristics of the Atlantic coasts. Wave data summarized from National Data Buoy Center buoys. H_mO and T_p averaged from hourly statistics over total period of record from statistics computed by National data Buoy Center. Tide range for indicated stations from statistics presented in NOAA Tide Tables

The Atlantic & Gulf of Mexico: Coral and Mangrove Coasts

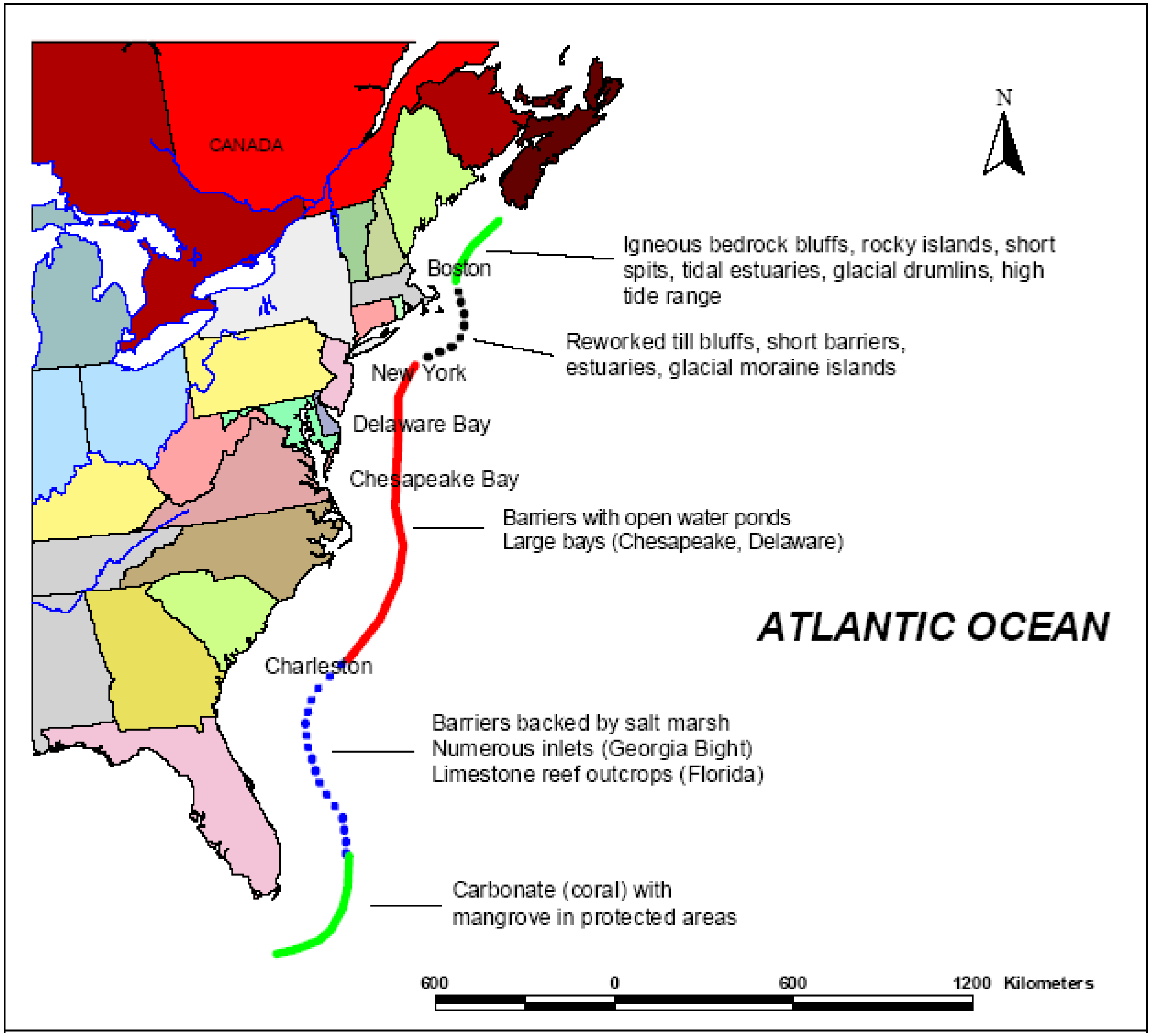


Figure I-2-1. Atlantic coast characteristics

- The barrier islands change from quartz sand south of Miami to carbonate-dominated sand, eventually transforming into coral keys and mangrove forest.

- Live reefs along the east and south side of the keys and the shallows of Florida Bay studded with mangrove islands extending north and west into the Everglades and the Ten Thousand Islands area that comprises the lower Florida Gulf of Mexico coast.

Gulf of Mexico: Wetland Mangrove, and Barrier Coasts

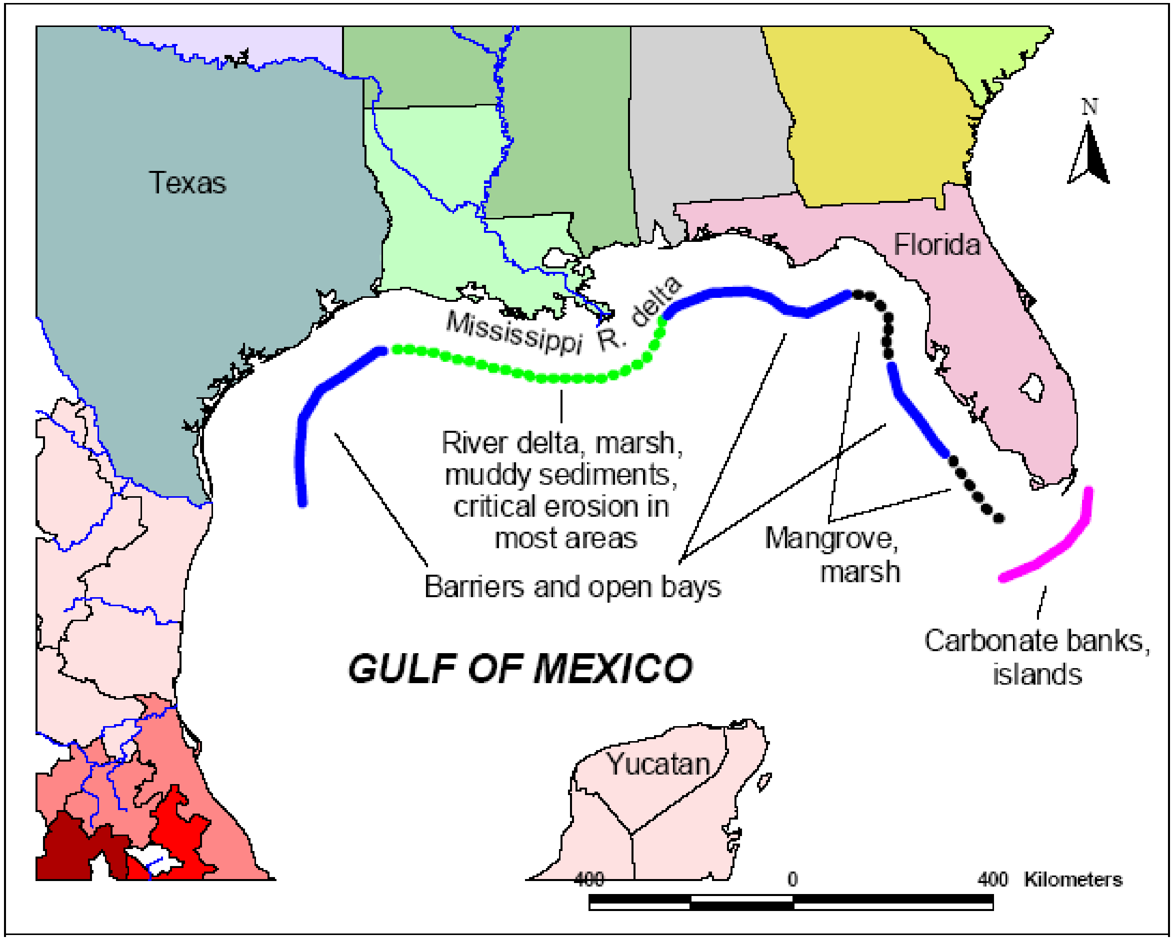


Figure I-2-8. Gulf of Mexico coastal characteristics

Sand supply is limited (limestone bedrock), so barriers are present only where there is a significant source, otherwise the coast is characterized by swamps.

Enclosed bays usually have an abundance of mangrove islands and the topography is low with many lakes and marshes.

Low wave energy environment.

The Mississippi River has built a series of deltas into the Gulf of Mexico, the most recent Balize Delta (bird foot) has an average age of 1500 years.

Most of the greater Mississippi delta is marshland and mud flats, with numerous shallow lakes and intertwining channels.

Gulf of Mexico West: Barrier Coast

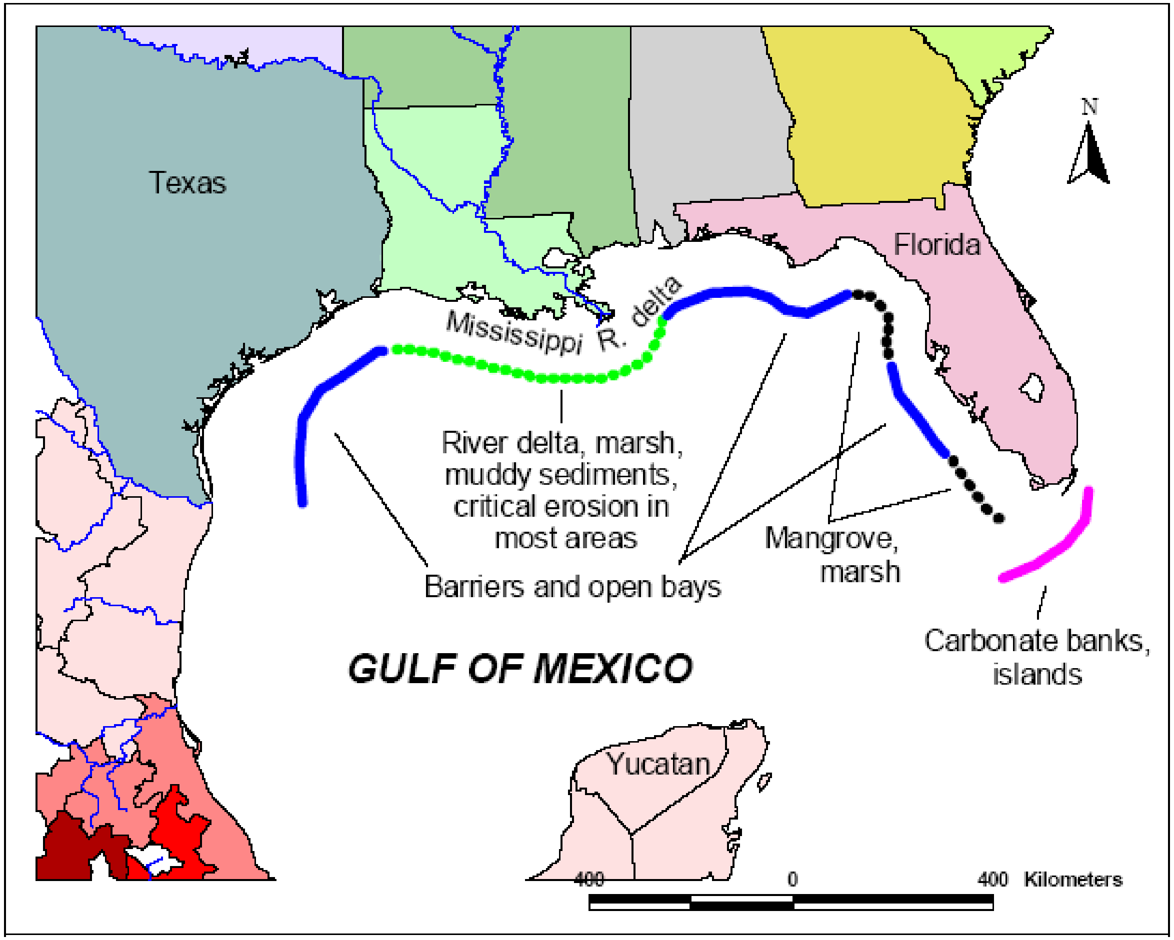


Figure I-2-8. Gulf of Mexico coastal characteristics

- Barrier Island become the dominant coastal feature from the Mississippi Delta through Texas.

- Some of the longest barrier islands in the world are located along the Texas coast. Padre Island and Mustang Island, combined, extend for 208 km and feature extensive dune fields behind the broad beaches. The dunes rarely rise more than 10 m in height, and many marshy wash-over deltas have extended into the large lagoons behind the barriers.

- Extreme wind driven circulation. A large part of Laguna Madre is only inundated during flood periods or when the wind blows water from Corpus Christi Bay onto the flats.

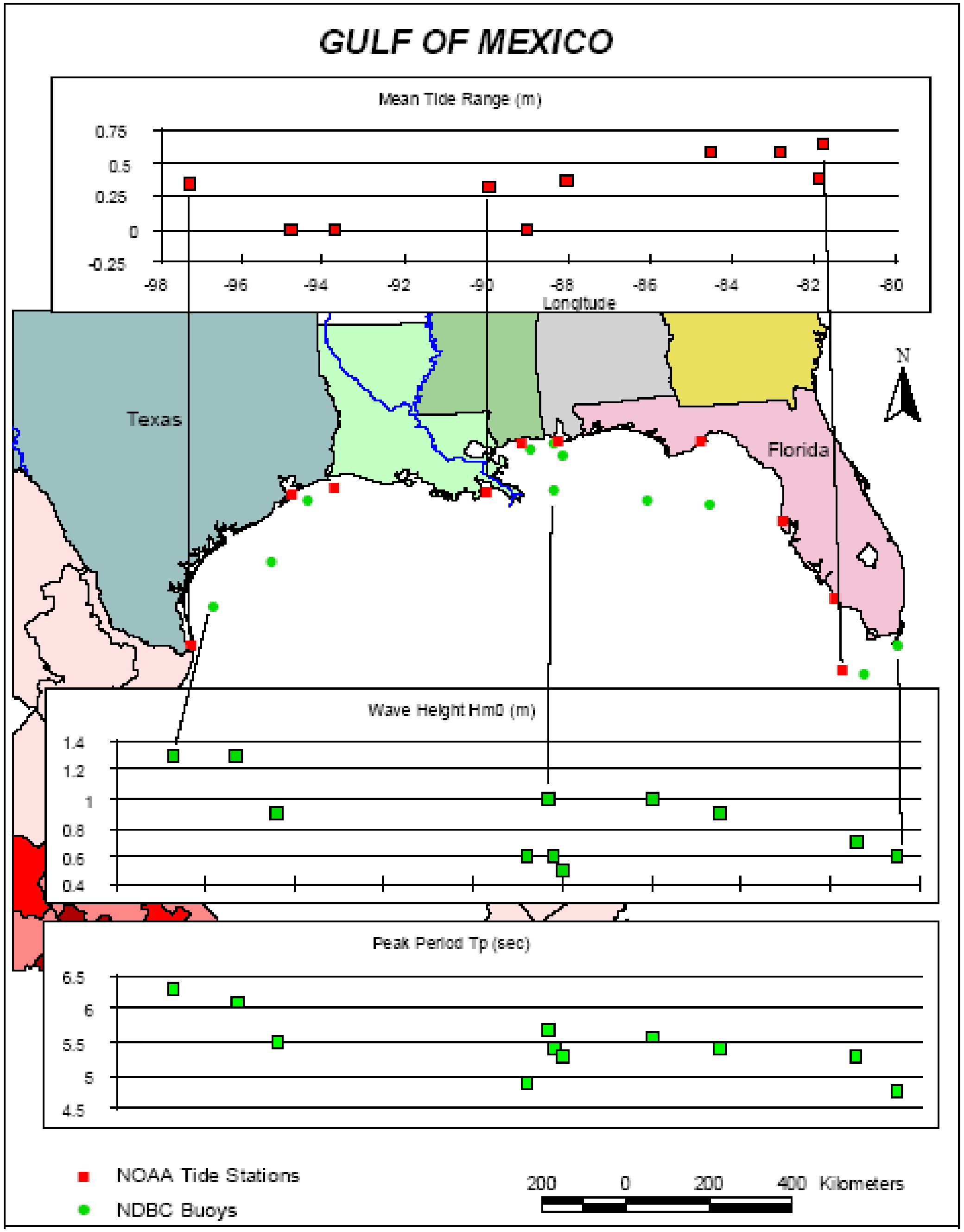


Figure I-2-9. Tide and wave characteristics of the Gulf Coast

Pacific: Sea Cliffs and Terraced Coasts

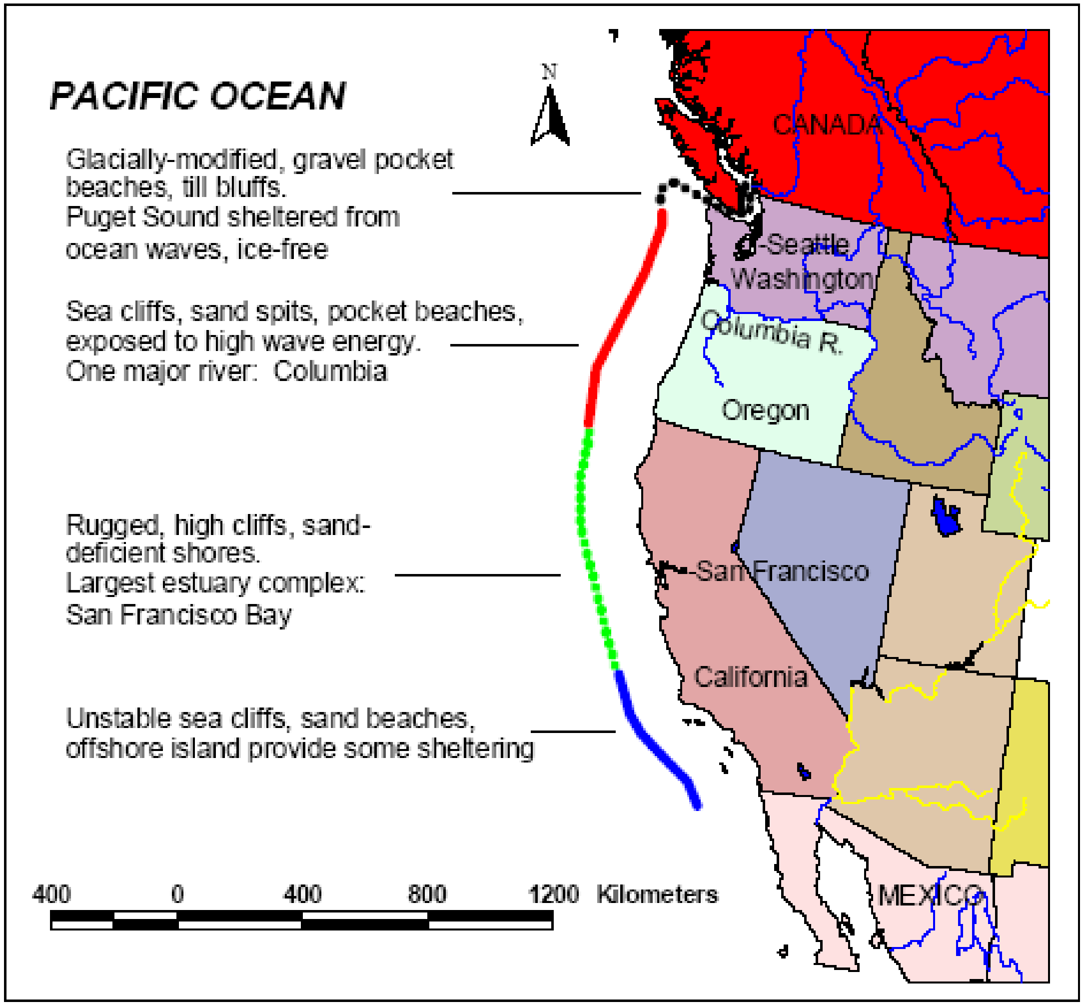


Figure I-2-13. Pacific coastal characteristics

- Low sea cliffs bordered by terraces and a few coastal plains and deltas compose the coasts of southern California.
- Sea cliffs in this area are actively eroding, particularly in areas where they have been cut into alluvium.
- Despite the presence of a series of regional mountain ranges that cut across the coast, the rugged central and northern California coast is one of the straightest in the world. This area has high cliffs with raised marine terraces. A few broad river valleys interrupt the mountainous coast.

Pacific: Sea Cliffs and Terraced Coasts

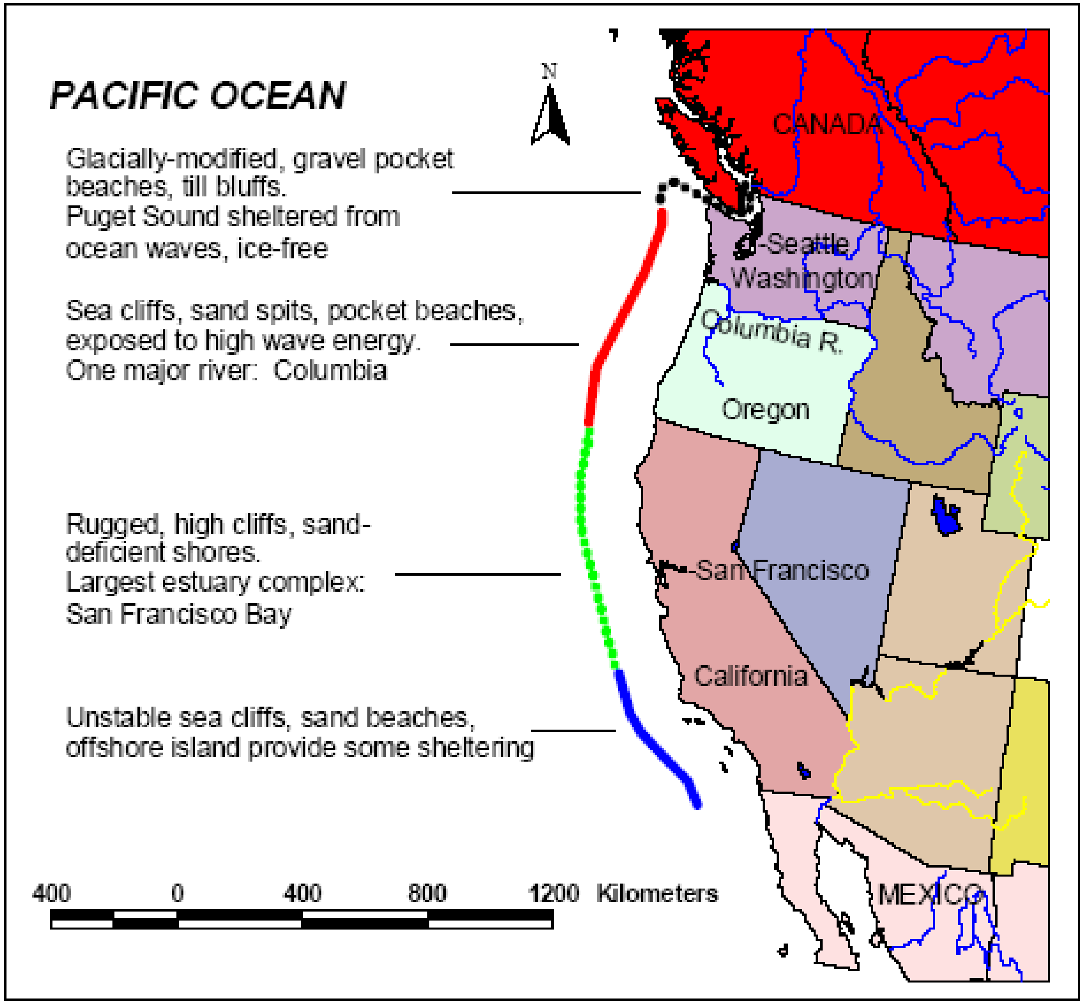


Figure I-2-13. Pacific coastal characteristics

- North of Cape Mendocino, the coast trends almost directly north, through Oregon and Washington, to the Strait of Juan de Fuca. Barriers or spits have formed at river mouths.

- Because of the North Pacific Ocean harsh wave climate, all of the major cities in Oregon and Washington were founded in sheltered water bodies.

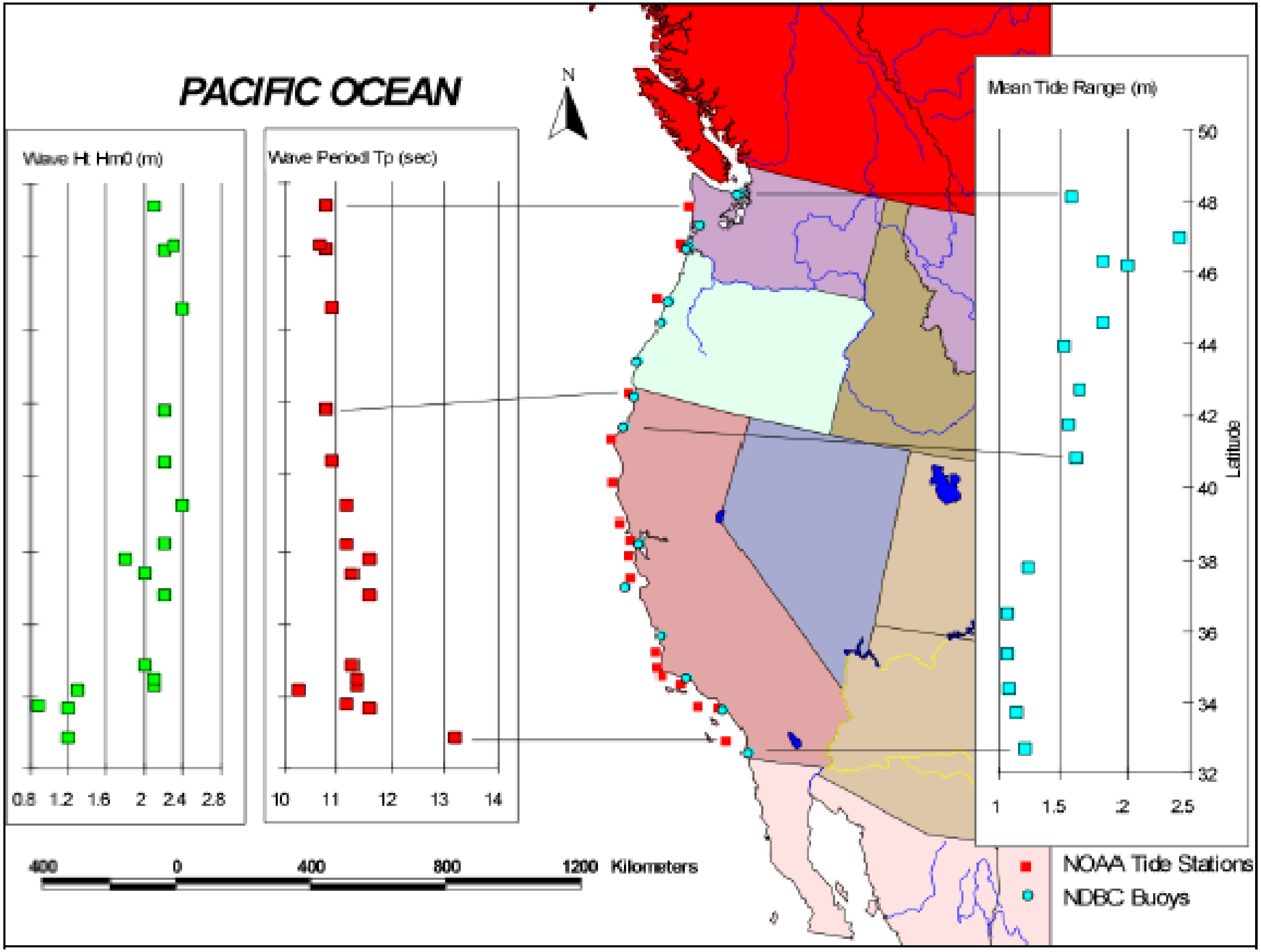


Figure I-2-14. Pacific coast tide and wave characteristics. The southernmost buoy shows high wave period because of the influence of swell waves and sheltering from wind waves provided by offshore islands

The Bering & Chukchi Seas: Arctic Coastal Plains & Barriers

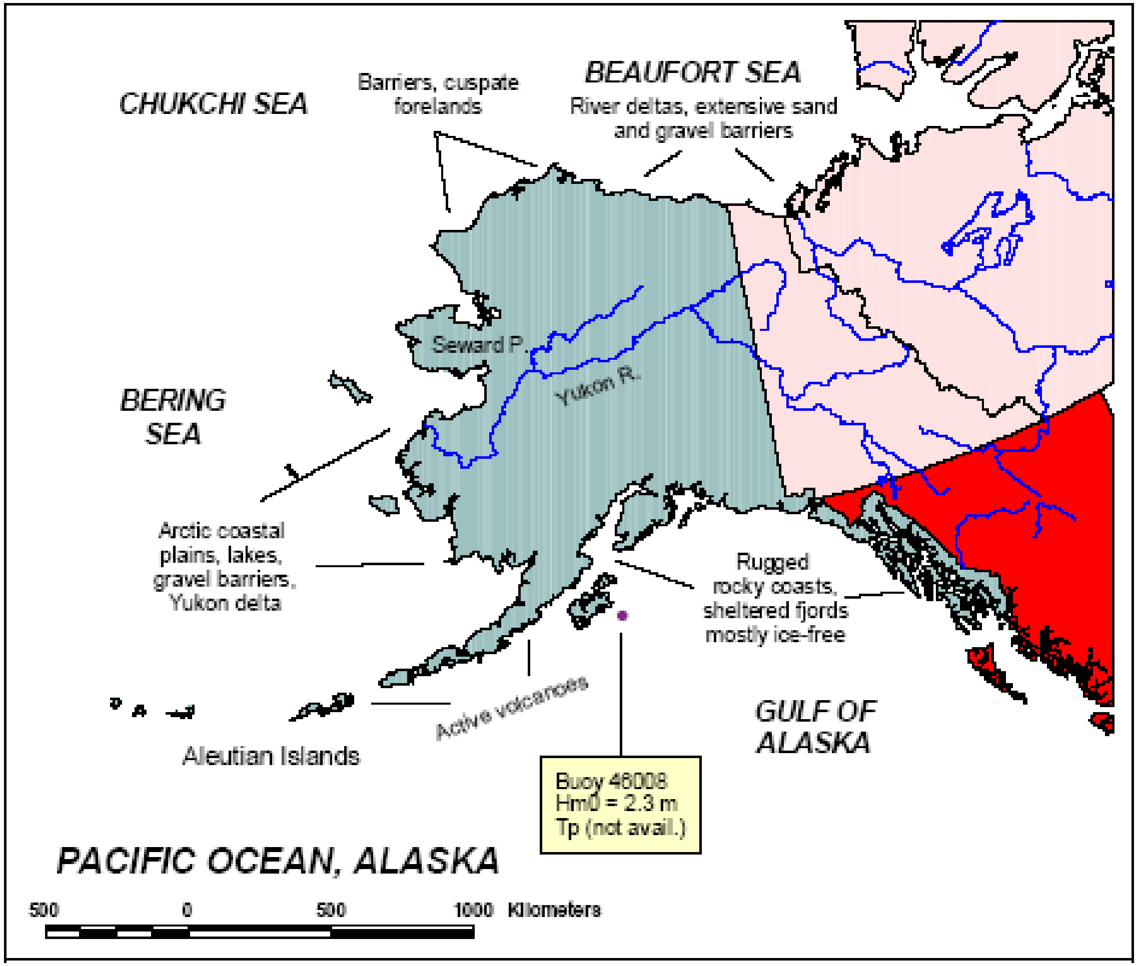


Figure I-2-18. Alaska coastal characteristics

- The volcanic Aleutian Mountains extend some 2200 km (1370 miles) forming the border between the Pacific Ocean and the Bering Sea.
- Beyond the Alaska Peninsula and bordering the Bering Sea, extensive coastal plains are found with numerous lakes and meandering streams.
- The Yukon River has formed a large delta with many old lobes that form a vast plain connecting small, elevated tracts.
- In the north permafrost melting in summer creates *thaw lakes.*
- North of Kotzebue Sound, barriers and cuspate forelands border the coast.

The Beaufort Sea: Deltaic Coast

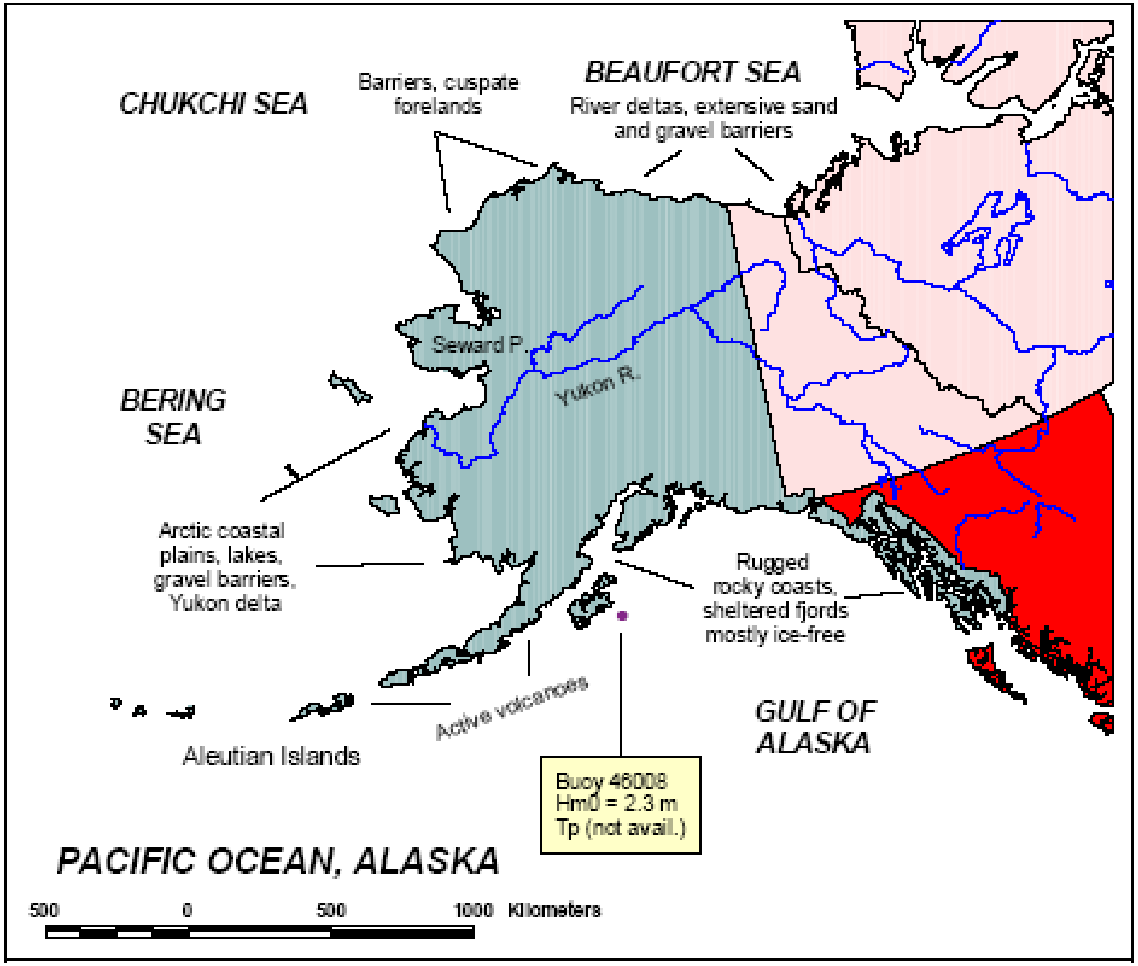


Figure I-2-18. Alaska coastal characteristics

- East of Point Barrow, the coast is dominated by river deltas.
- Rivers draining the Brooks Range and the northern Canadian Rockies, built these deltas even though the rivers flow only a short period each year.
- Where the deltas are not actively building into the sea, extensive barrier islands can be found.

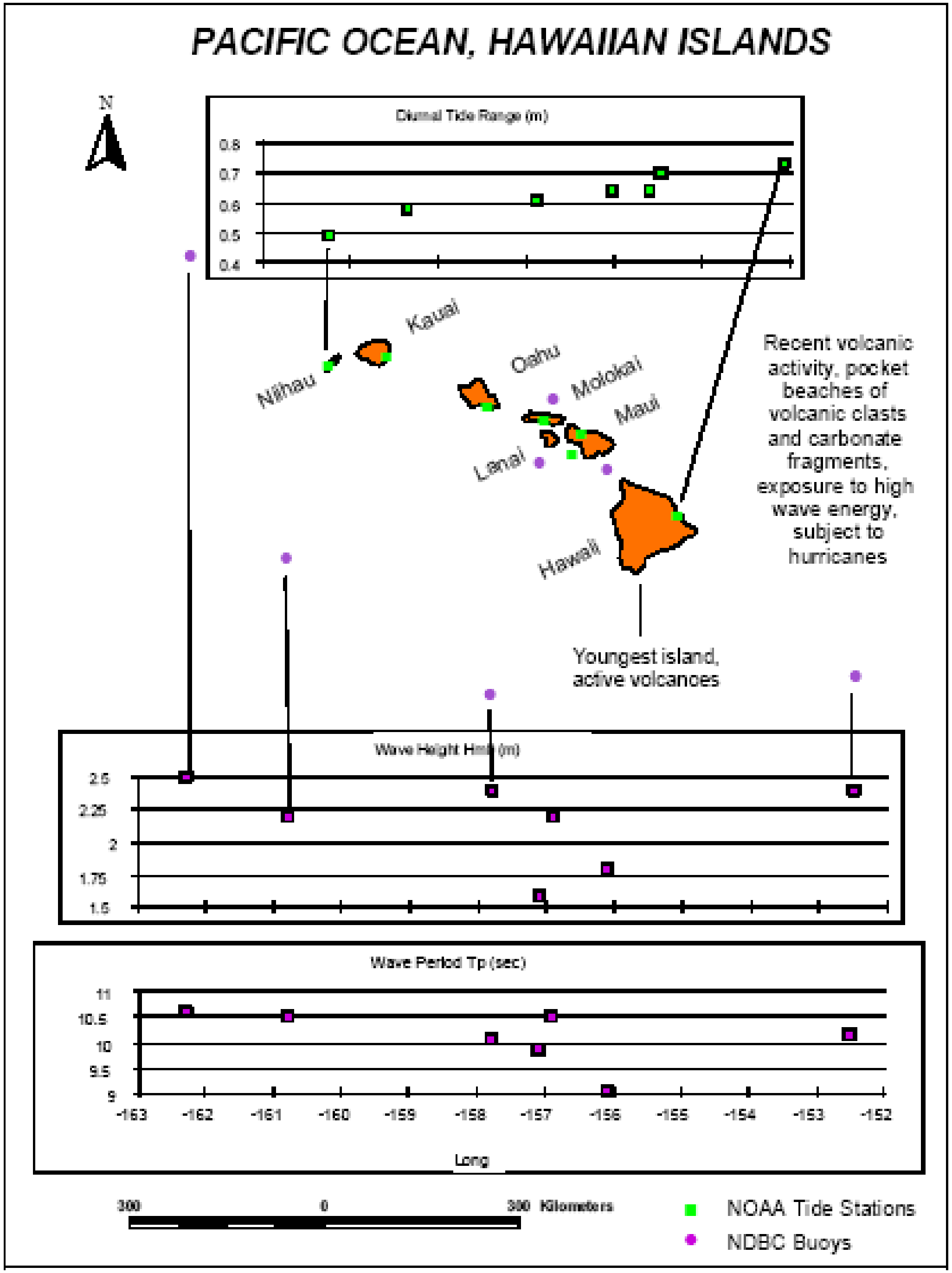


Figure I-2-19. Hawaiian Islands wave characteristics

- About 20 percent of the 1,650 km of shore on the main islands is sandy beach.
- The Hawaiian Islands are the tops of volcanic mountains rising above the ocean floor about five km below the water surface. These volcanoes formed over a localized hot spot of magma generation.
- As the older volcanoes formed great shields and died, the movement of the ocean floor and crust moved them to the northwest. A higher percentage of sand shores are found on the older islands.
- The sand on the beaches primarily calcareous and of biologic origin, where river outlets are present, smaller pocket beaches of volcanic sand may be found.

Figure I-2-20. Great Lakes shoreline characteristics

- They have a combined surface area of 245,300 km2 (94,700 miles2), making them the largest freshwater body in the world.

- The lakes range in elevation from about 183 m for Lake Superior (International Great Lakes Datum 1985) to about 75 m for Lake Ontario, with the largest drop in elevation, 51 m between Lakes Erie and Ontario at Niagara Falls (CCEE 1994).

- Geologically, the Great Lakes are relatively young, having been formed by glacial action during the Pleistocene period.

- The shores of the Great Lakes and other freshwater lakes in the United States and throughout the world are as diverse as the ocean shores, featuring high and low erosive and non-erosive cliffs and bluffs, low plains, sandy beaches, dunes, barriers and wetlands.