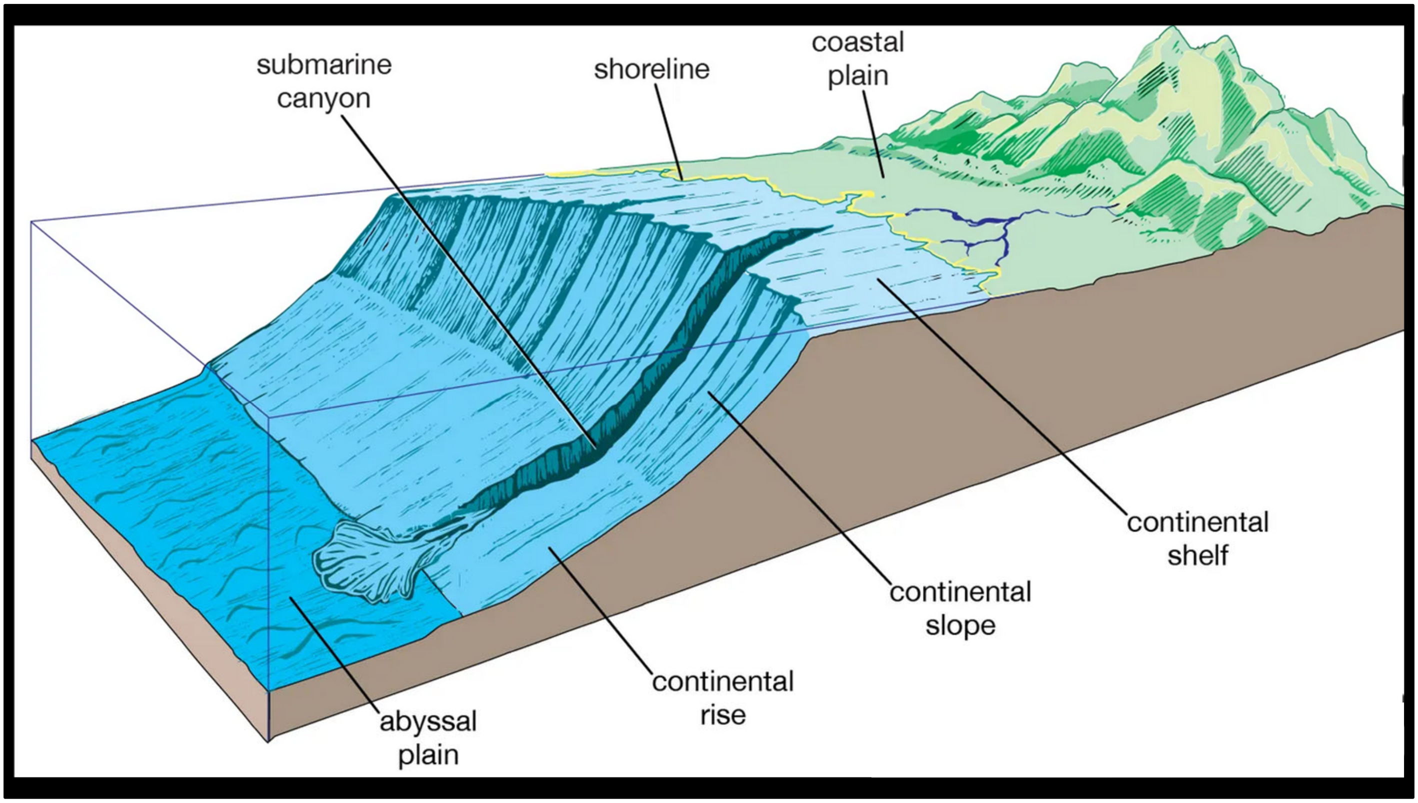
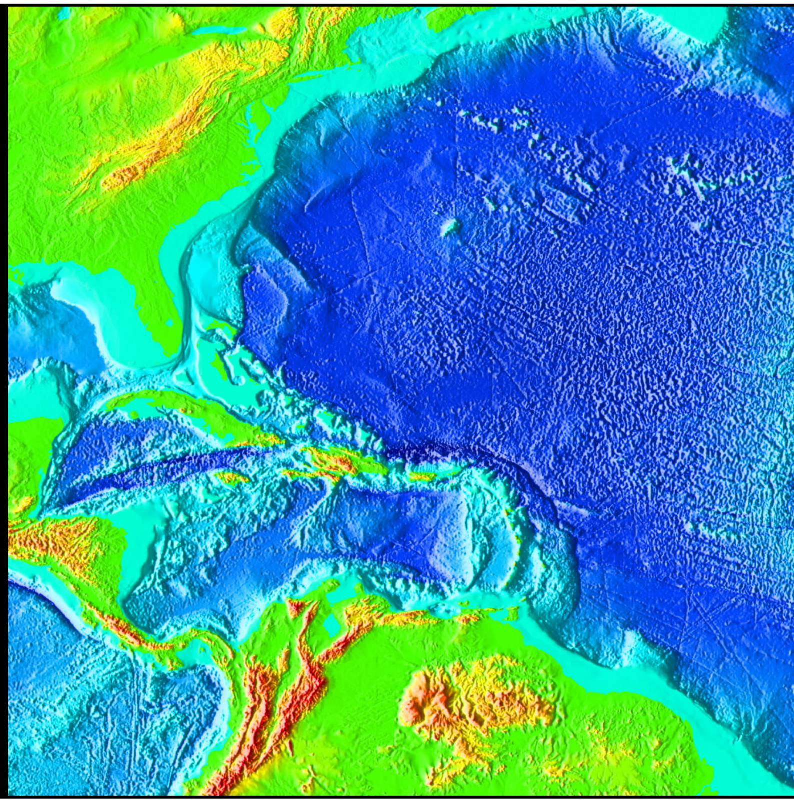
Coastal landforms and processes

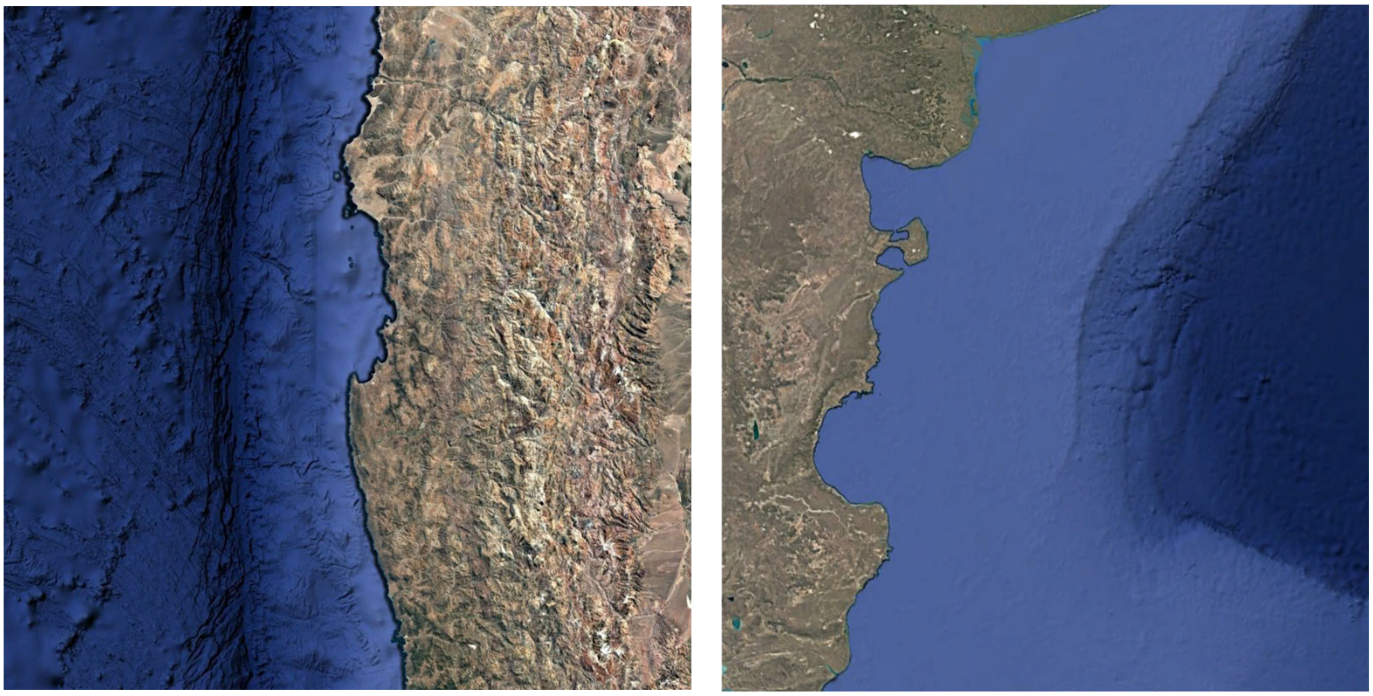
- Coast is contact zone between land, air, and sea.
- Dynamic interaction of:
  - Tectonics and crustal motion
  - Energy supplied by ocean water: tides, waves, ocean currents.
  - Sediments and nutrients supplied by erosion from continents via fluvial transport

Sand dune along the coast of the Netherlands (left), Great Sand Dunes National Monument, Colorado (right).


submarine
canyon
shoreline
coastal
plain
continental
shelf
continental
slope
continental
rise
abyssal
plain

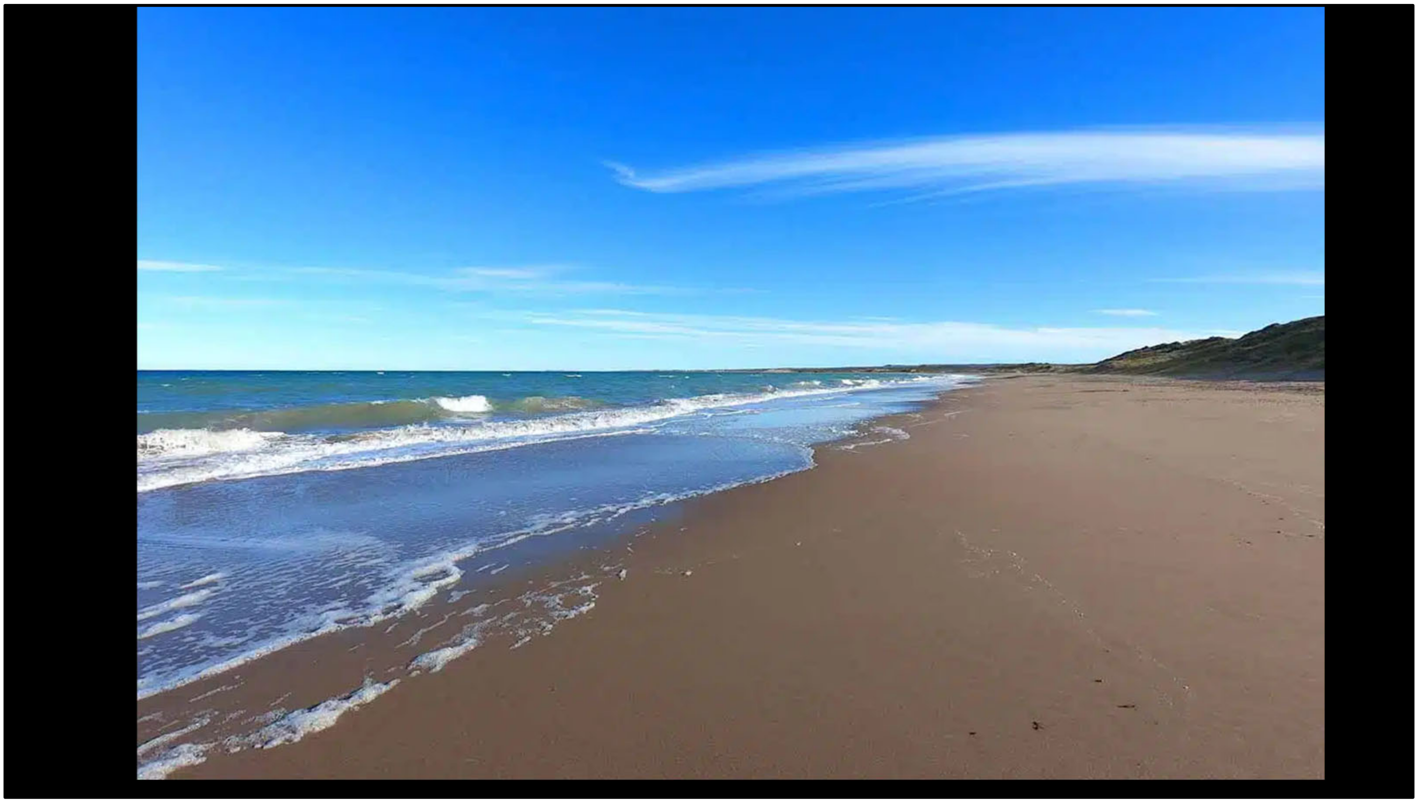


Identify:
Continental shelf
Continental slope
Abyssal plain



Types of coast: tectonically active vs tectonically passive coast (South America, west coast on left; South America, east coast on right)

Coastal Chile, an tectonically active coast

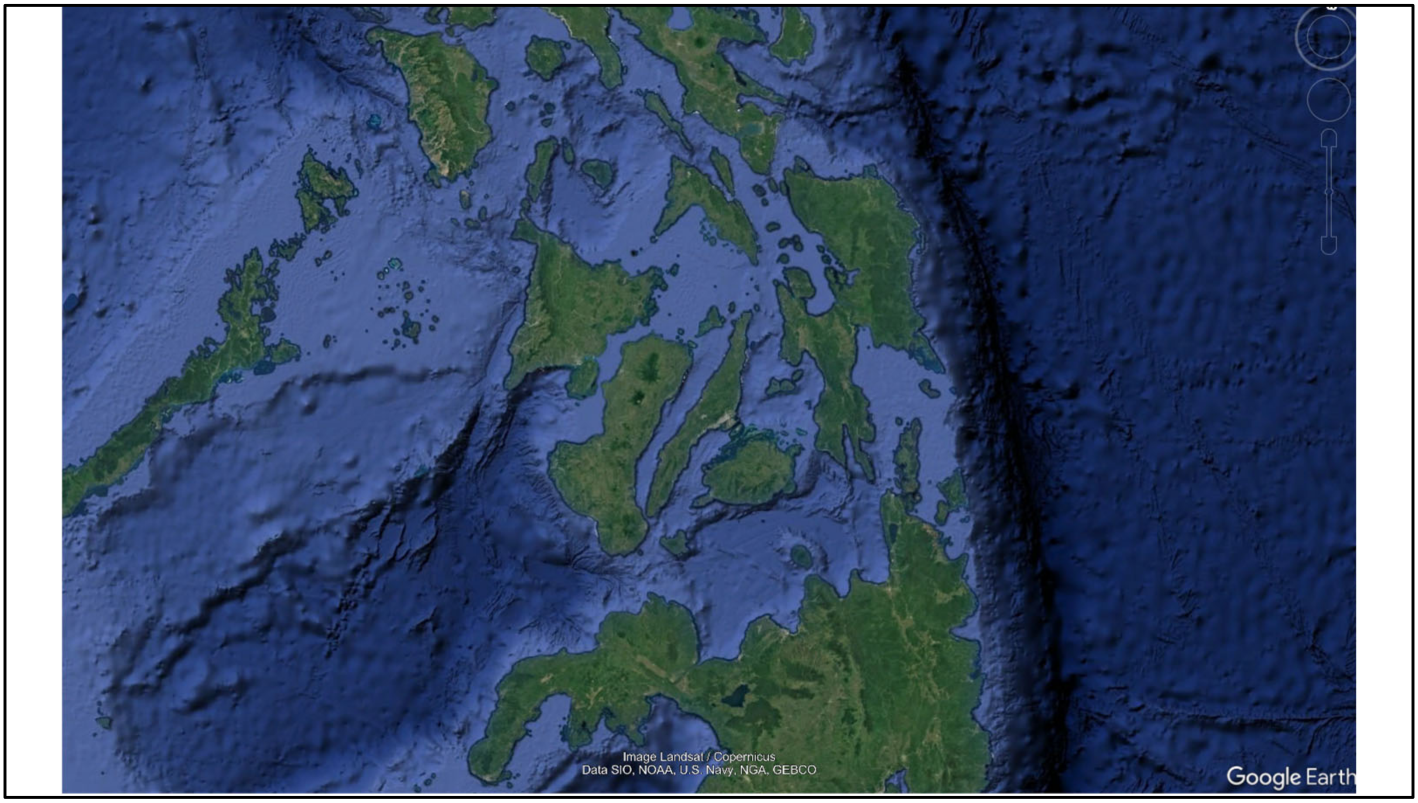


Types of coast: emerging or subsiding

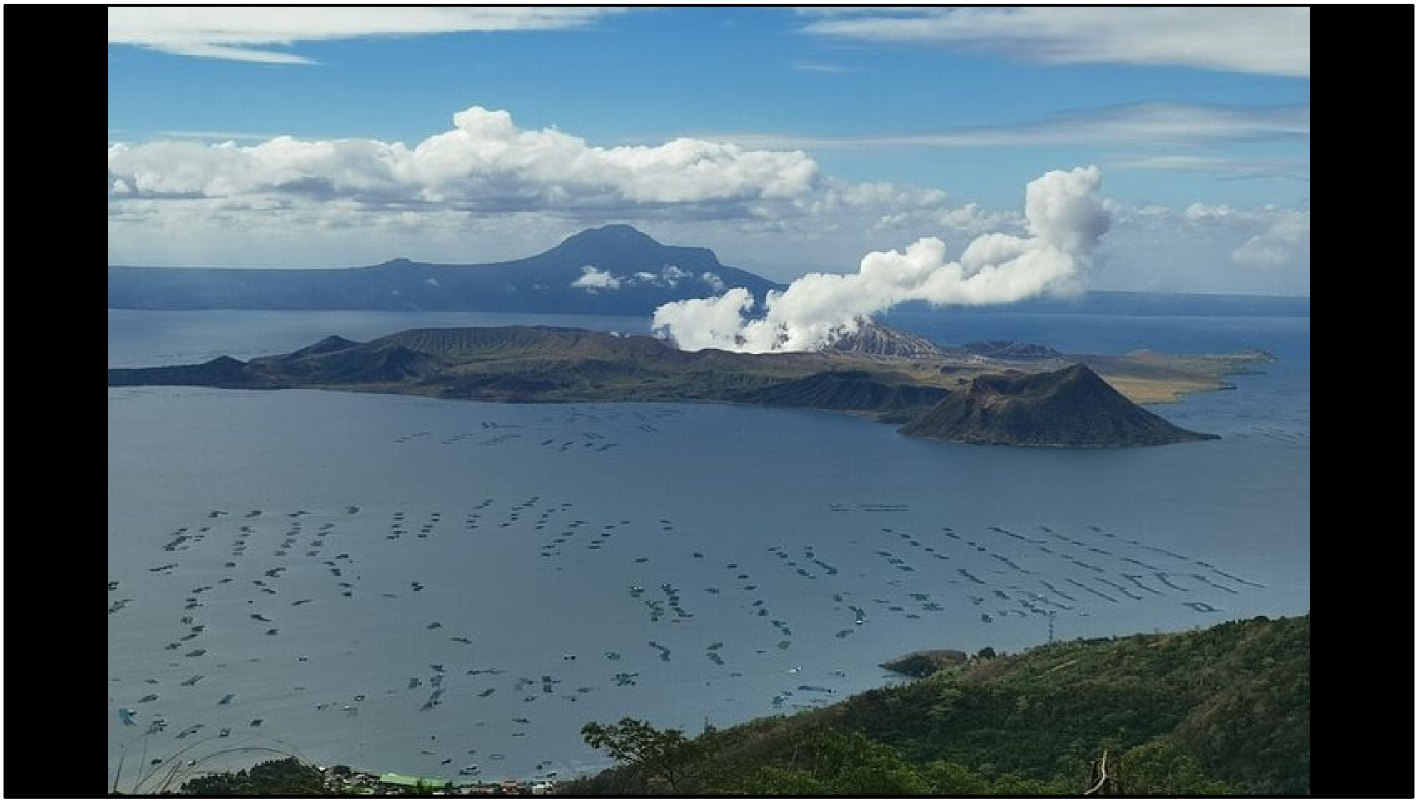
The Pacific Coast of California and in particular the Big Sur region is an emergent coast. This area is characterized by tectonic uplift caused by movements along the San Andreas Fault and other fault systems, resulting in rising coastal land and the creation of rugged coastal cliffs.

The Mississippi Delta region in Louisiana is a subsiding coast. This coast is subsiding due to sediment compaction, extraction of groundwater and hydrocarbons, and the natural settling of deltaic deposits. Combined with rising sea levels, this leads to significant coastal subsidence.

Subsiding coastline of the Mississippi Delta.



Islands of the nation of the Philippines



Taal Volcano in Taal Lake on Luzon in the Philippines

Many of the larger islands of the Philippines are actively uplifting as a result of tectonic forces. These islands are located at the convergence of several tectonic plates, including the Eurasian Plate, the Philippine Sea Plate, and the Sunda Plate. The islands' setting results in complex interactions, including subduction, faulting, and orogenic (mountain-building) processes. The Philippine Fault System, which runs along the length of the Philippine archipelago is one of the major structures contributing to tectonic uplift. Additionally, subduction zones, such as the Manila Trench to the west and the Philippine Trench to the east, generate compression and stress that contribute to vertical uplift and deformation of the landmass over time. These tectonic processes have significant geological consequences, such as the formation of mountain ranges, increased seismic activity, and volcanic activity, which contribute to the dynamic topography and ongoing uplift of the Philippines

https://youtu.be/wC38s1mVfpw?si=f_i6n6JSAQE2iVwb

- The coast around Manila is subsiding even though it is found in a tectonically active emergent coastal region
- Groundwater pumping has caused the land to sink around cities
- 4-5 million people in the capital city of Manila depend upon these pumps
- Wealthier neighborhoods and businesses are hooked up to a public water system that pipes in water from inland lakes
- Sea levels have risen here, but human-causes subsidence is much faster
- New foundations are added to keep homes above flood levels

.

This is occurring in many other large coastal Asian cities, liked Jakarta in Indonesia.

Fish ponds also use groundwater and additionally contribute to ground subsistence.

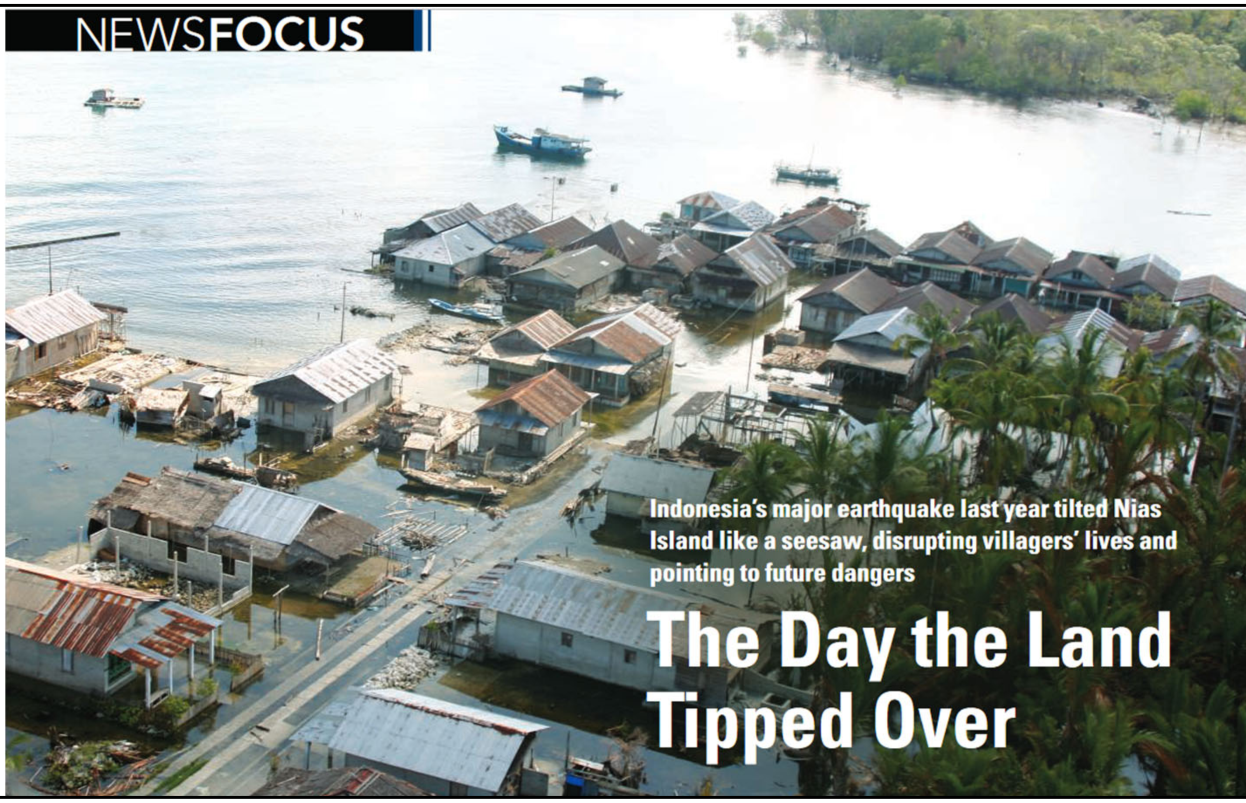
The main sources of metro Manila’s piped water supply are dams. The water from these dams are then processed and piped into homes and businesses.

A significant portion of Manila's population depends on groundwater for their water supply, though the exact number can vary based on different estimates and data sources. In Metro Manila, rapid urbanization and an inadequate centralized water supply system have led many residents, especially in certain areas, to rely on local pumps and private wells for their daily water needs.

According to various studies and reports, a substantial share of the population, particularly those in more informal or peripheral areas, still uses groundwater due to limited access to piped water services. It's estimated that 30% to 40% of the population in Metro Manila may rely on groundwater as a primary or supplementary water source. This dependence is higher in areas with inadequate infrastructure or where formal water services are not consistently available.

This reliance on groundwater has led to significant challenges, including the over-extraction of aquifers, which can cause subsidence (ground sinking) and increase vulnerability to flooding and seawater intrusion. The long-term sustainability of this practice is a concern for city planners and environmental regulators.

Jakarta is another city that is sinking because of groundwater withdrawal.



Earthquake-related coastal subsidence and emergence

Some places subsided during megathrust rupture: The village of Haloban in the Banyak islands sank 0.62 m (2.0 feet)

http://www.tectonics.caltech.edu/sumatra/Science/index.html

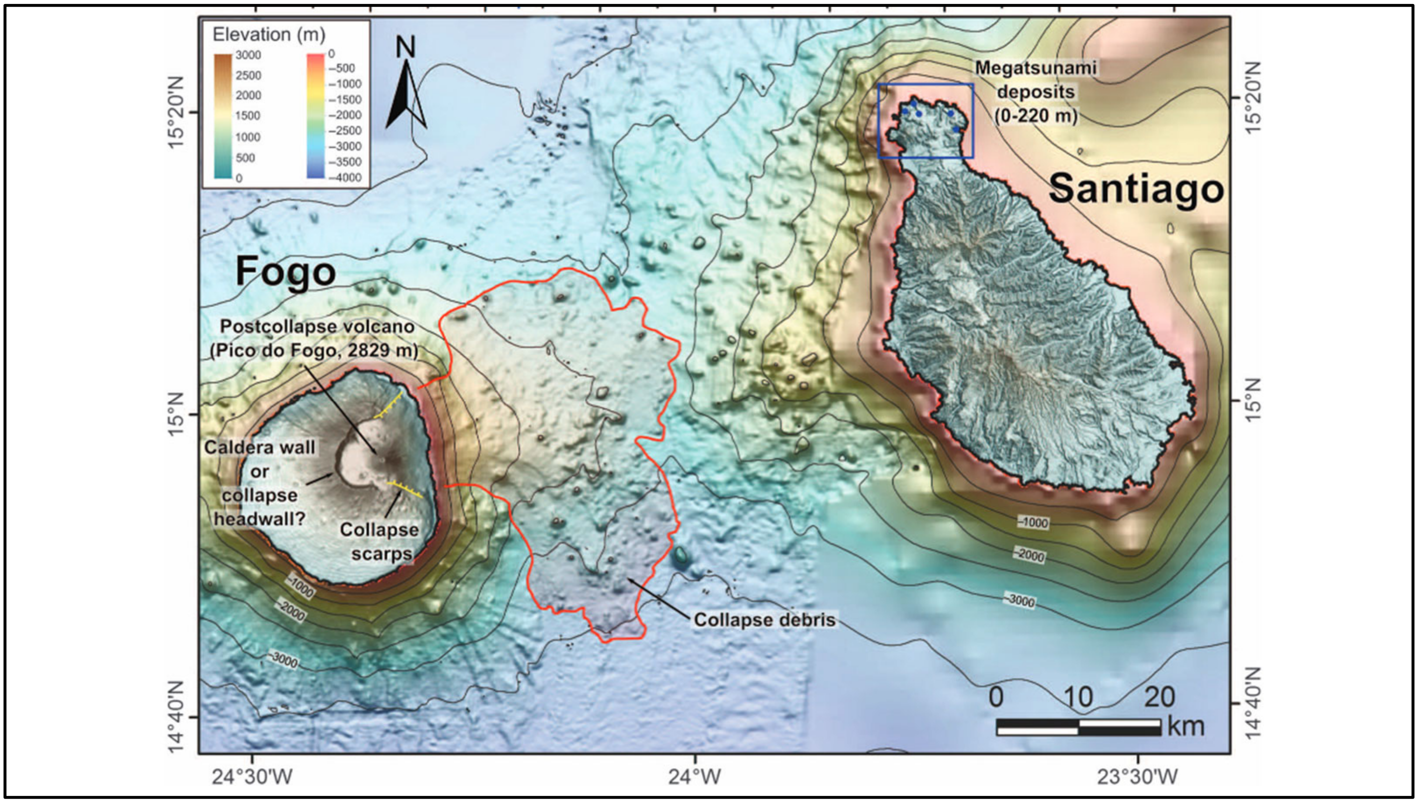
Left: Before the March 2005 earthquake, the southwestern coast of Nias island was slowly subsiding, as evidenced here by a stand of dead coconut palms seaward of the beach (upper photo). During the earthquake, the coast rose about 2.5 m, elevating the dead grove and neighboring coral reef out of the surf zone and re-uniting the small islands in the background with the mainland of Nias Island.

Right: Children atop coral uplifted 1.74 m (5.7 feet)in the Hinako islands, west of Nias island, Indonesia

2011 Japan

The collapse of this volcanic caldera triggered a massive tsunami 73,000 years ago (Fogo, in the Cape Verde archipelago)

https://www.science.org/content/article/ancient-tsunami-heaved-700-ton-boulders-over-island-cliffs



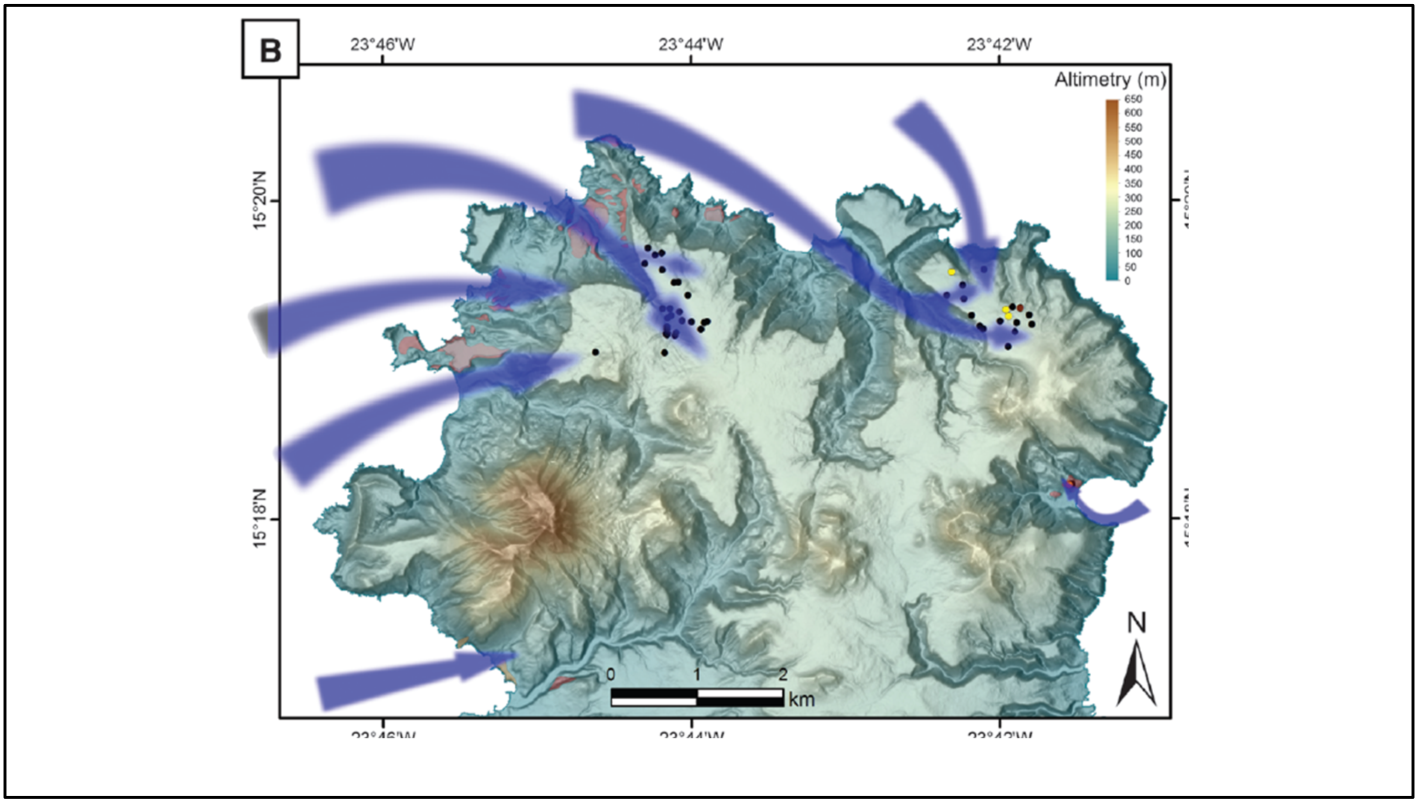
These are part of the Cape Verde islands


A
4.2 m
7.5 m
6.0 m

https://www.washingtonpost.com/news/energy-environment/wp/2015/10/02/scientists-say-an-ancient-megatsunami-flung-boulders-nearly-as-high-as-the-eiffel-tower/
https://www.science.org/content/article/ancient-tsunami-heaved-700-ton-boulders-over-island-cliffs

Ramalho, R. S., Winckler, G., Madeira, J., Helffrich, G. R., Hipólito, A., Quartau, R., ... & Schaefer, J. M. (2015). Hazard potential of volcanic flank collapses raised by new megatsunami evidence. *Science Advances*, *1*(9), e1500456.

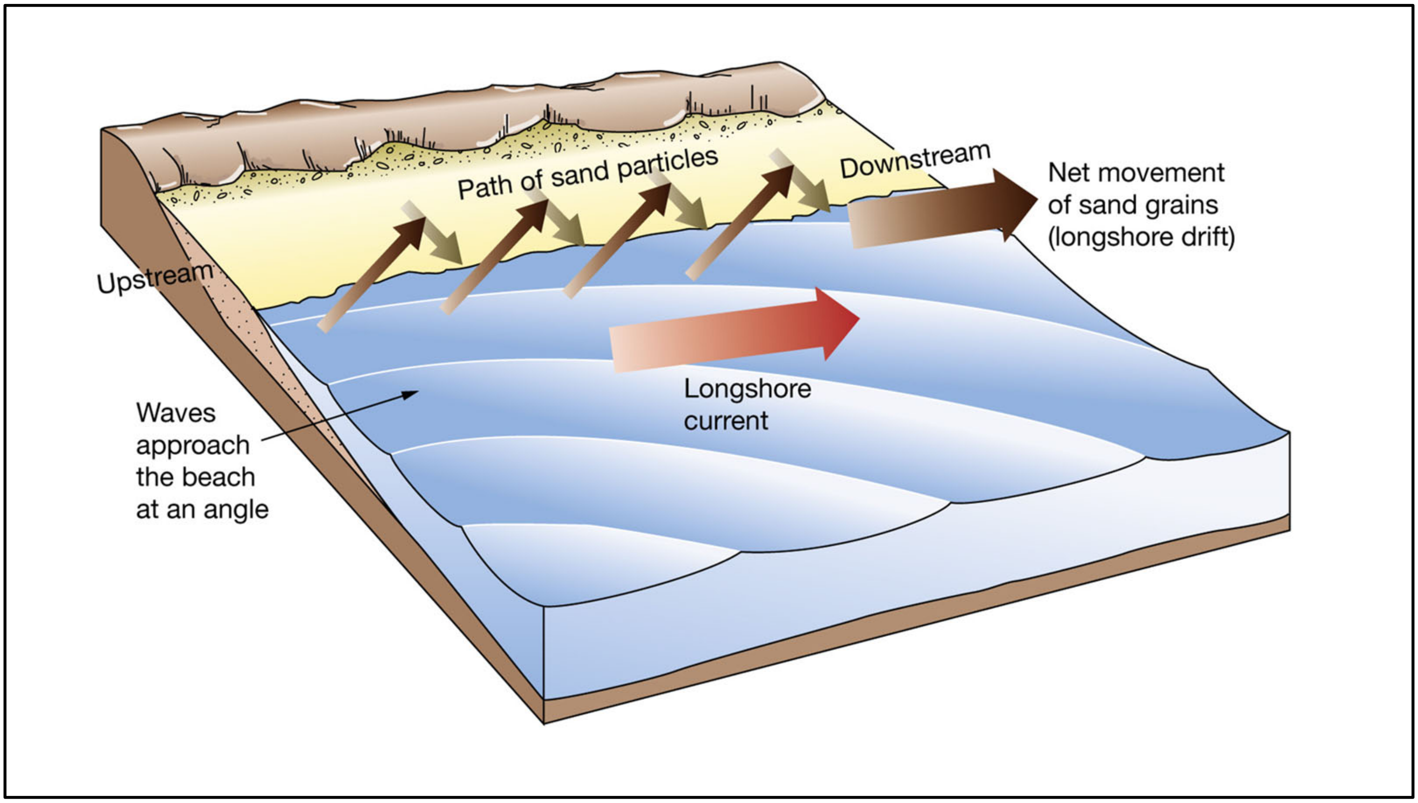
Tsunamic boulders are also called megaclasts



Interpreted tsunami inundation pattern denoting a western-approaching tsunami that refracted along Santiago’s northern shore, caused flooding of the northwest-oriented valleys, and subsequently spilled over the plateau.

Wave refraction, Rincon, Santa Barbara. Surfers ride these ‘point breaks’ , that location where the wave starts to build as it contacts the shallow water. Surfers travel in the direction the wave is breaking, in this case, to the right it you were surfing or to the left of the image. The surfer tries to stay at that point where the wave has built up from shallower water but is also continuing to break because of the angle of the wave relative to the shoreline and water depth.


WHAT IS...
SWASH & BACKWASH?



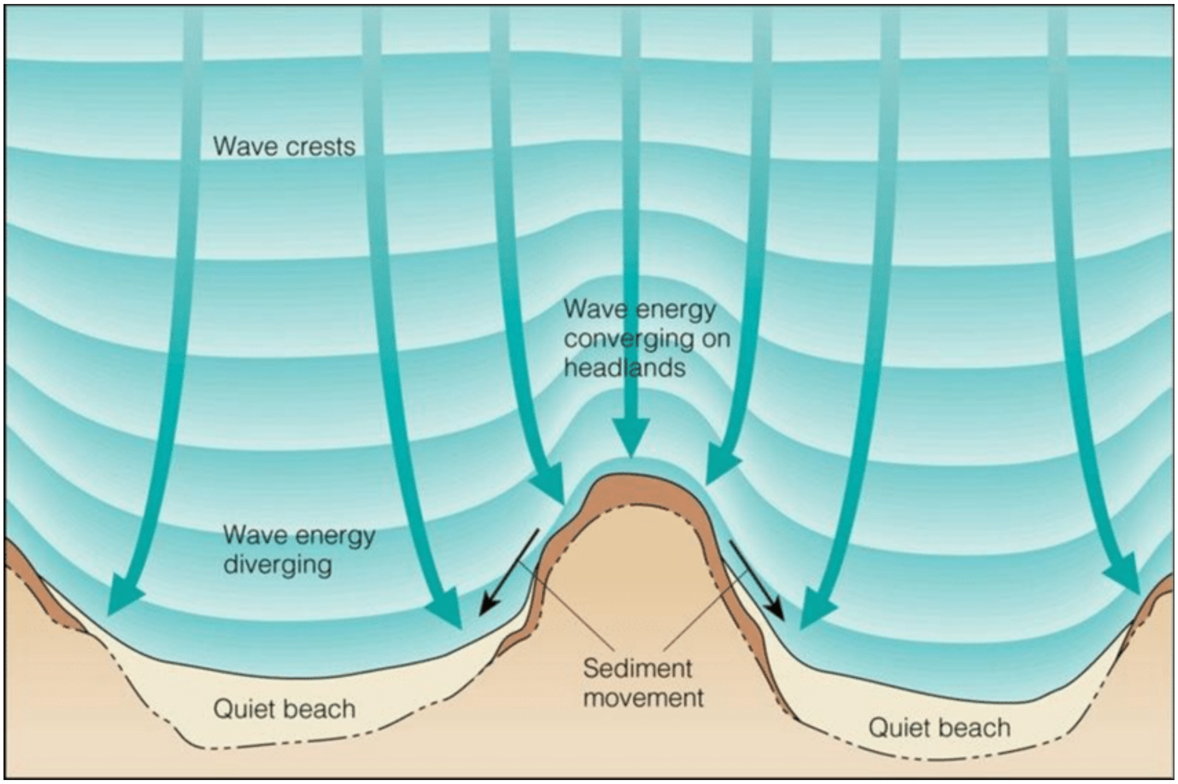
Longshore drift and sediment transport

Swash and **backwash** are terms that describe the movement of water on a beach, influenced by waves approaching the shoreline.

This is the movement of water that rushes up the beach after a wave breaks. Swash travels at an angle determined by the wave's direction and energy, carrying sand, pebbles, and debris up the beach. It plays a role in building up the beach profile, especially during calmer weather when waves have lower energy, allowing sand and other materials to accumulate.

After the swash moves up the beach, gravity pulls the water back down toward the sea in a process called backwash. This movement flows perpendicular to the shoreline, regardless of the angle of the swash, and can carry some sand and sediment back down into the ocean. During high-energy conditions, like storms, backwash is often stronger, leading to erosion as it pulls sediment back into the sea.

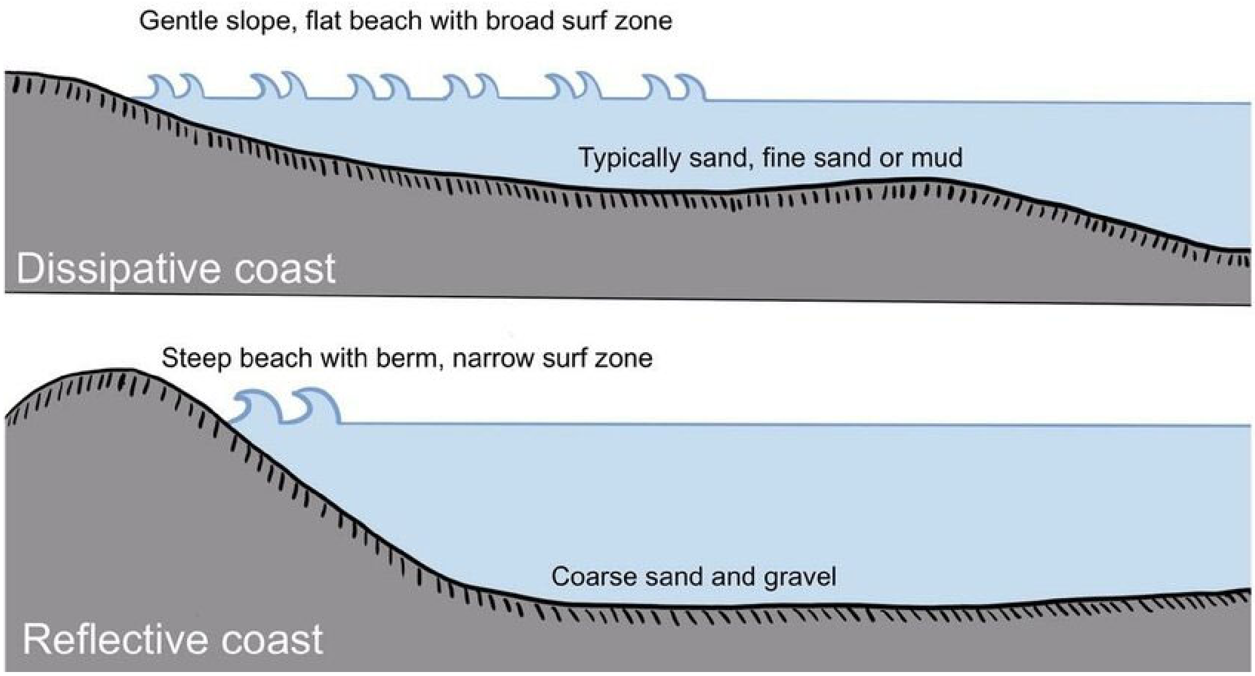
Together, swash and backwash shape beaches by building them up or eroding them, depending on the balance between the two processes and wave conditions.



Wave refraction

Headland-bay coast. Wave energy is focus on the headland, which erodes and then the sediment is transported

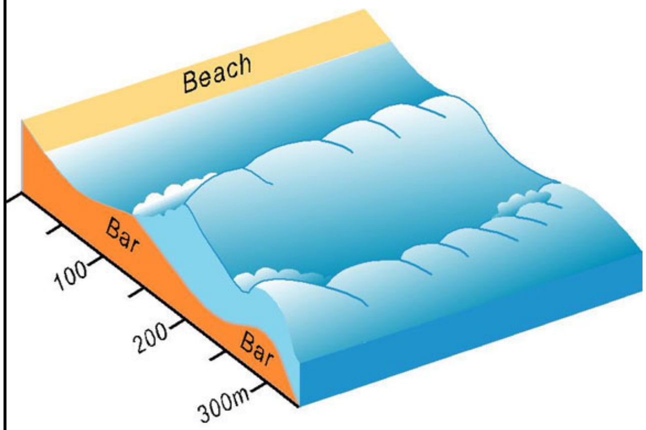
Lenan Head and Dunaff Head, from the summit of Urris Hill on the Inishowen Peninsula, County Donegal in Ireland.



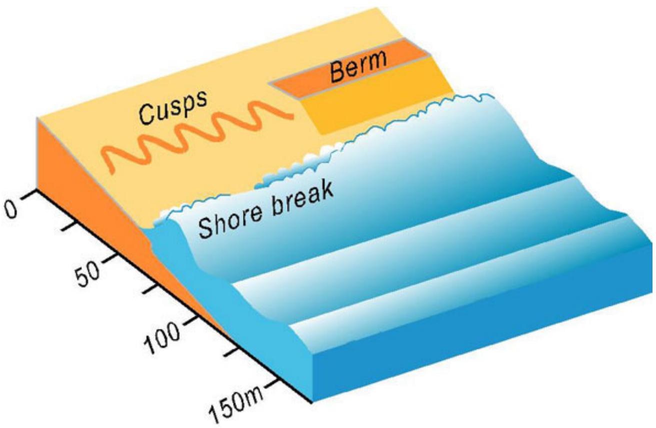
Reflective and dissipative coasts

Dissipative beaches are characterized as being high energy beaches with a wide surf zone (300-500 m) including two to three shore normal bars and troughs, and a low-sloping and wide beach face consisting of fine sand.

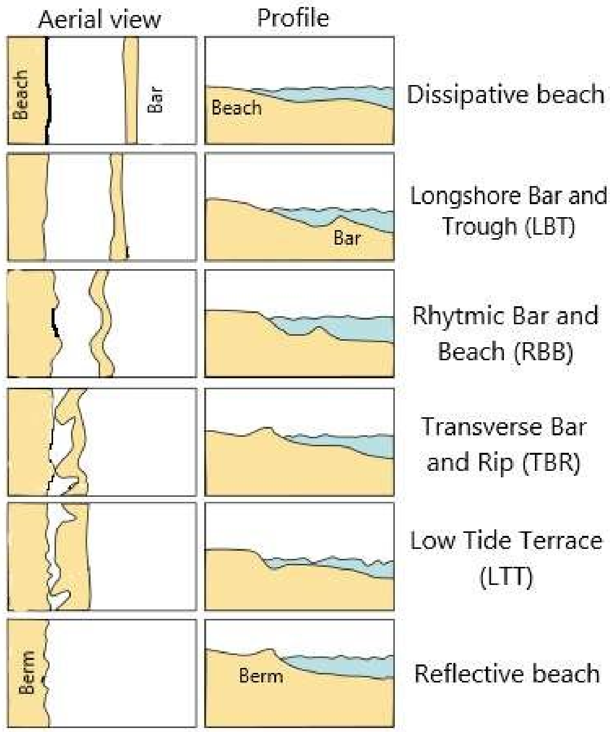
Reflective beaches are characterized by a relatively steep narrow beach face, composed of coarse sand, and a narrow surf zone. Waves break close to the shore on a reflective beach with little prior loss of energy. Deep water is close inshore.

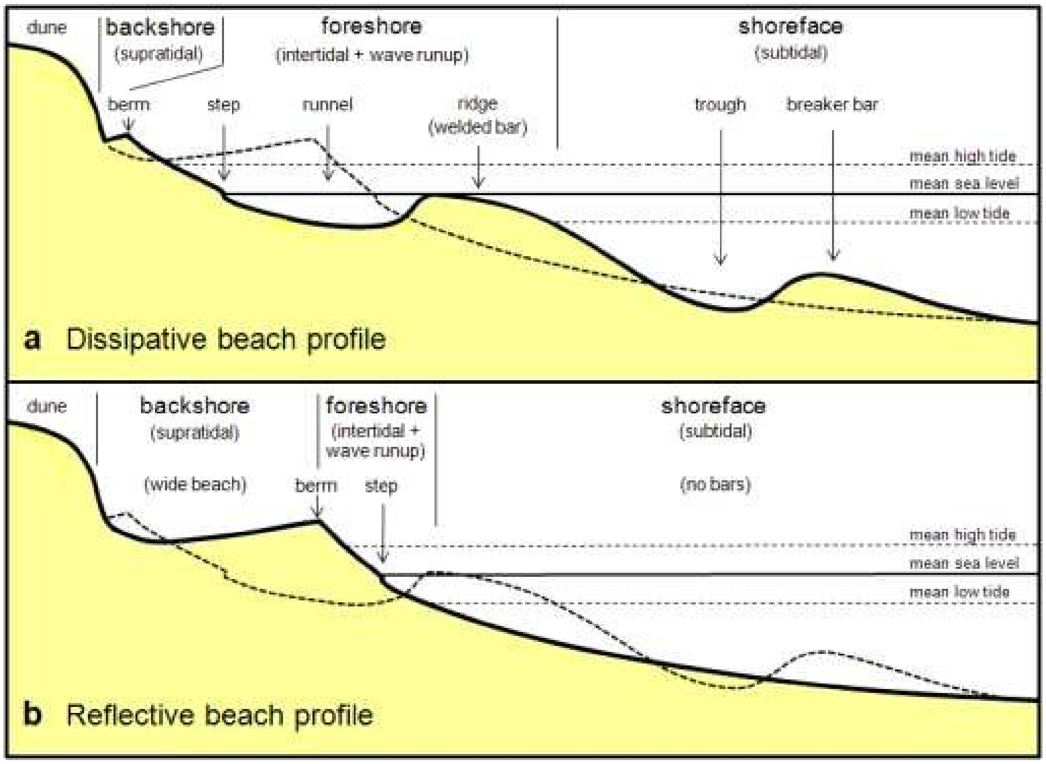


Dissipative https://ozcoasts.org.au/conceptual-diagrams/science-models/beaches/wdb/



Reflective beach
https://ozcoasts.org.au/conceptual-diagrams/science-models/beaches/wdb/

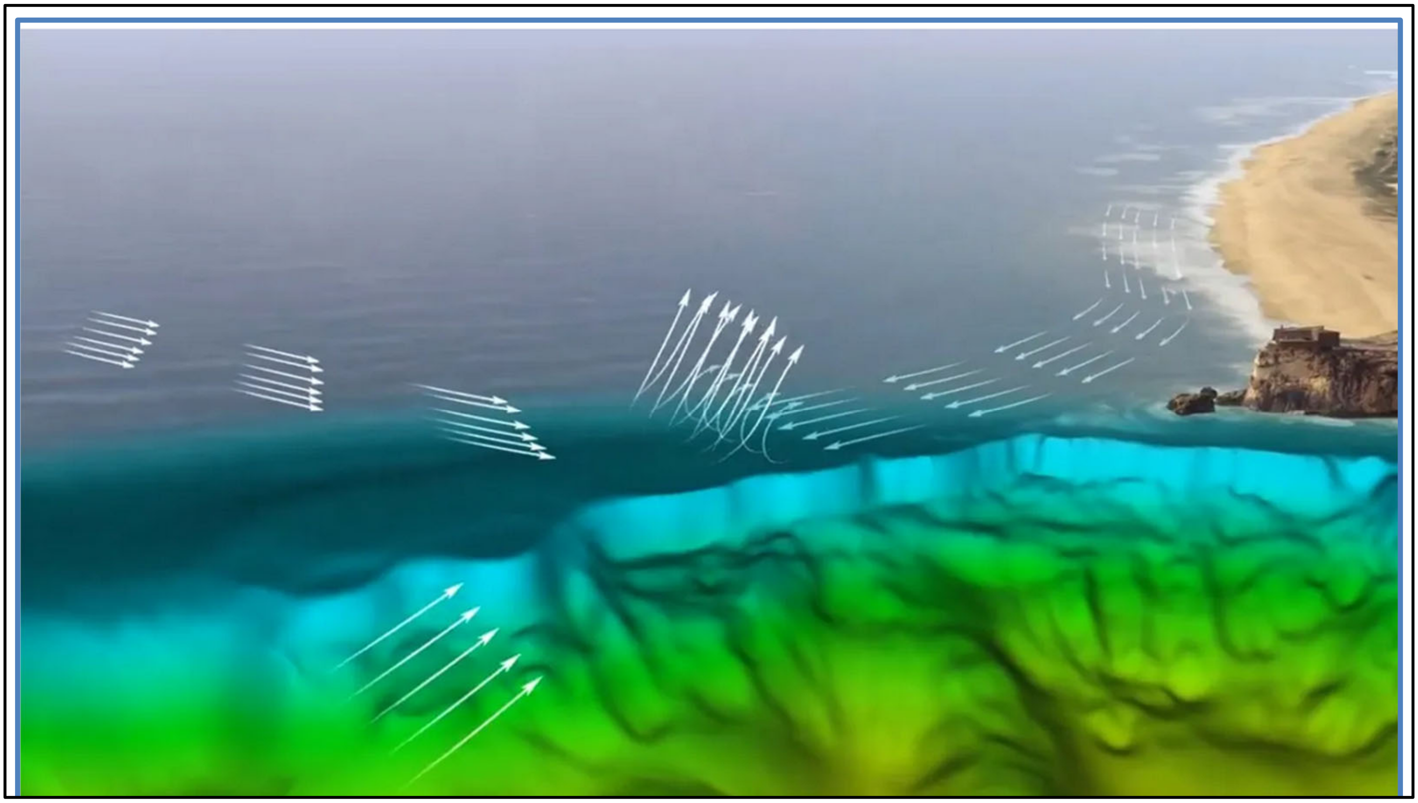

Aerial view
Profile
Beach
Bar
Beach
Dissipative beach
Longshore Bar and Trough (LBT)
Bar
Rhytmic Bar and Beach (RBB)
Transverse Bar and Rip (TBR)
Low Tide Terrace (LTT)
Berm
Berm
Reflective beach


dune
backshore
(supratidal)
foreshore
(intertidal + wave runup)
shoreface
(subtidal)
berm
step
runnel
ridge
(welded bar)
trough
breaker bar
mean high tide
mean sea level
mean low tide
a Dissipative beach profile
dune
backshore
(supratidal)
foreshore
(intertidal +
wave runup)
shoreface
(subtidal)
(wide beach)
berm
step
(no bars)
mean high tide
mean sea level
mean low tide
b Reflective beach profile

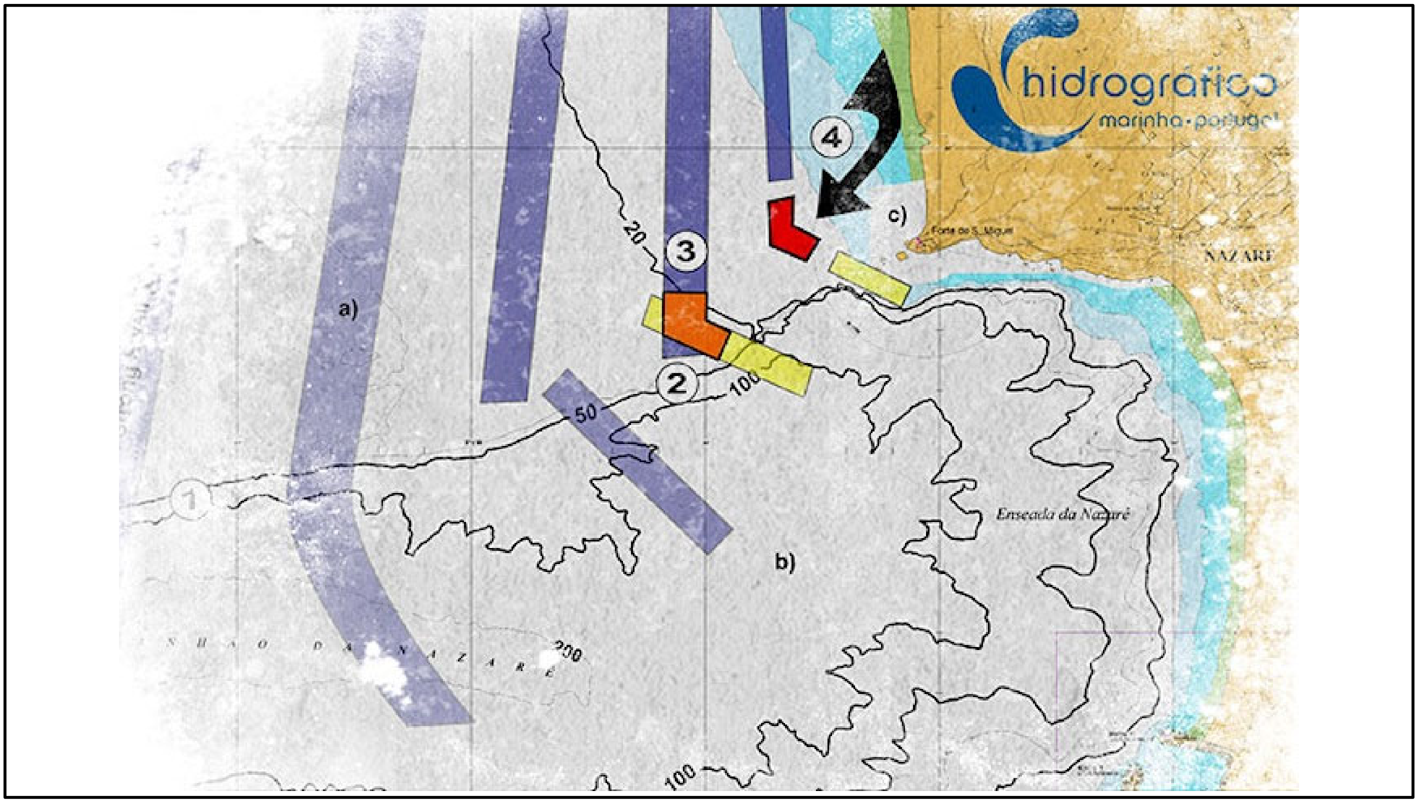
Sneaker waves are more common on reflective coastlines because wave energy can propagate through deep water closer to shore.

Praia do Norte ('North Beach') is a beach located in Nazaré, Portugal.

Big waves on a dissipative coastline (Portugal). How does this happen?



https://pogodnik.com/en/news/the-biggest-waves-in-the-world-are-off-nazare-portugal



https://www.surfertoday.com/surfing/the-mechanics-of-the-nazare-canyon-wave

Concordant and discordant coastlines

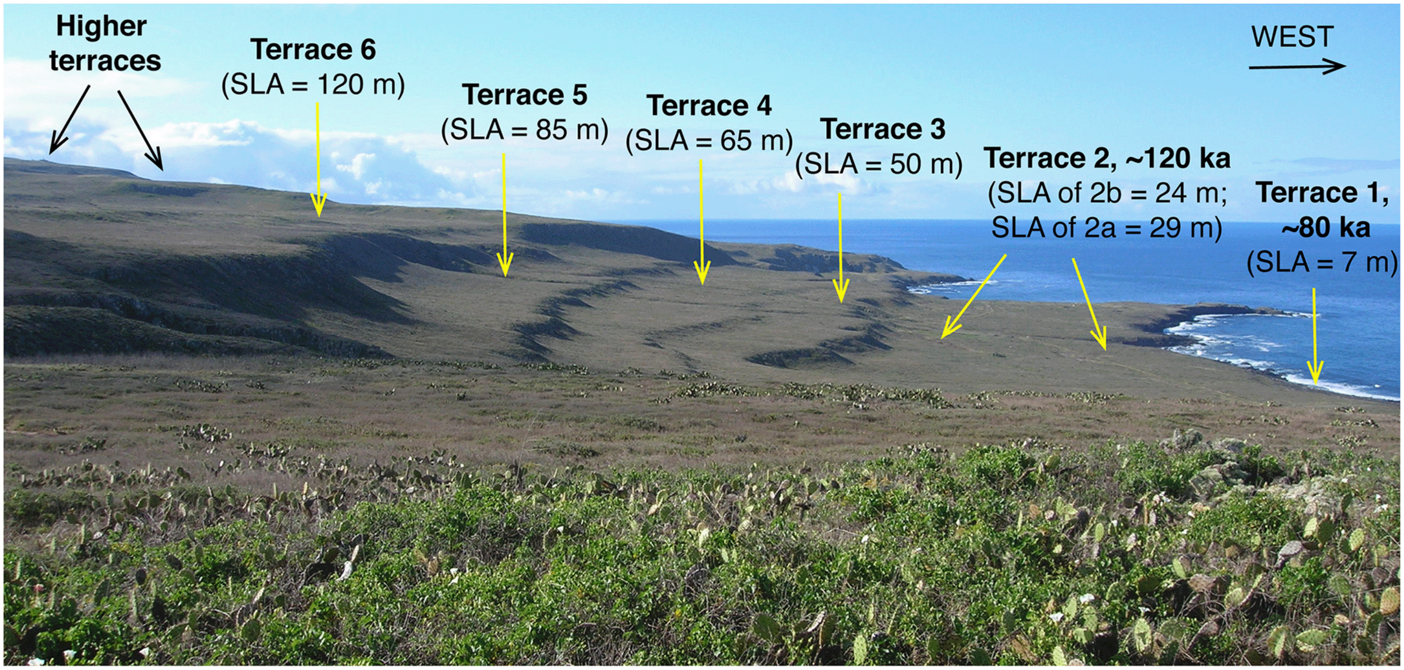
Concordant coastlines tend to have fewer bays and headlands, and coves. The geology alternates between bands of hard and soft rock on a discordant coast. The different resistance to erosion of these rocks leads to the formation of headlands and bays.

South Island of New Zealand is a discordant coast comprised of different rock and sediment types.

South Island surface geology is comprised of schists, sandstones, glacial till, alluvial and loess deposits, marine limestones and sandstones, basalt

Jutland Peninsula of Denmark is a concordant coast. It is mostly comprised of sediments derived from glacial erosion in the past.

Much of Jutland's surface geology is dominated by glacial till, a mix of clay, sand, gravel, and boulders left behind by glaciers during the last Ice Age. In some areas, especially central Jutland, there are extensive sand and gravel plains created by meltwater from retreating glaciers. Post-glacial sea levels also played a significant role in shaping Jutland, depositing layers of marine clay, sand, and silt, especially in low-lying areas near the coast.



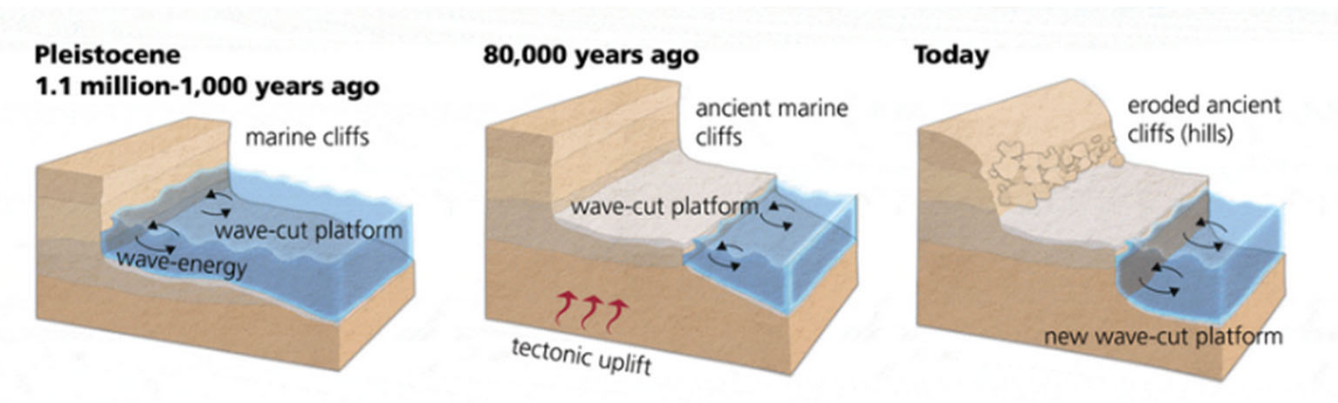
https://essd.copernicus.org/articles/14/1271/2022/

Coastal terraces on San Clemente Island, California

SLA is shoreline angle elevation about modern sea level. It marks the highest point that the waves reached during the formation of that terrace.

The terraces on San Clemente Island, California, were primarily caused by a combination of tectonic uplift and changes in sea level over geological time. The island is located within a tectonically active region along the boundary of the Pacific and North American plates, which contributes to gradual uplift. This process, combined with fluctuations in sea level due to glacial and interglacial cycles, has resulted in the formation of marine terraces.

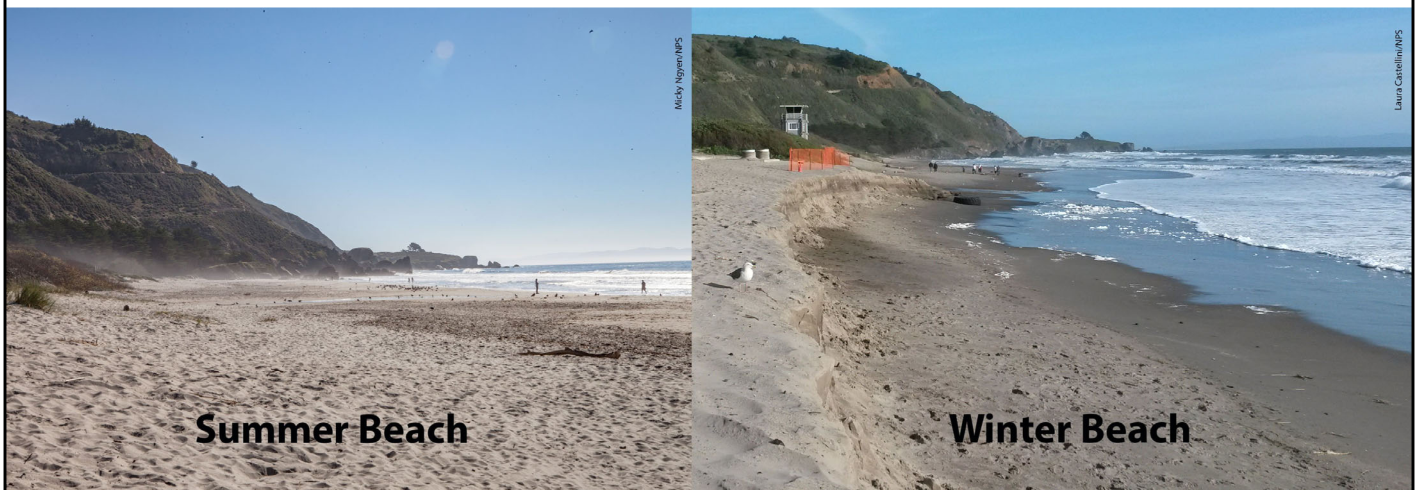
Marine terraces are created when waves erode a flat platform at the coastline, which is then raised above the current sea level due to tectonic activity. As this process repeats over time, a series of stepped terraces forms, each one representing a different period of sea level stability. San Clemente Island's terraces are evidence of these combined geological forces shaping the landscape over hundreds of thousands of years.

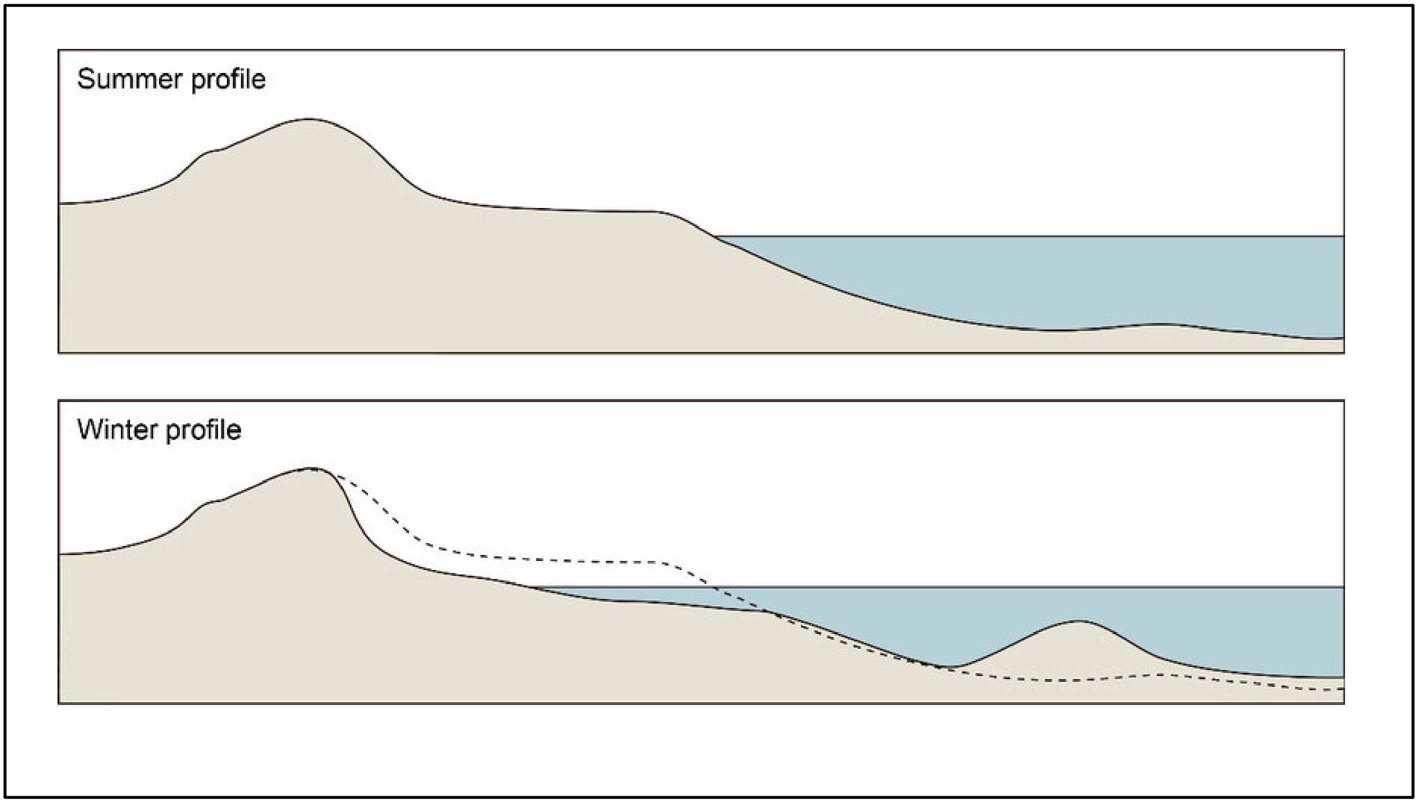


https://illustratingnature.com/portfolio-items/staircase-through-time/

Winter wave regime beach in La Jolla, CA

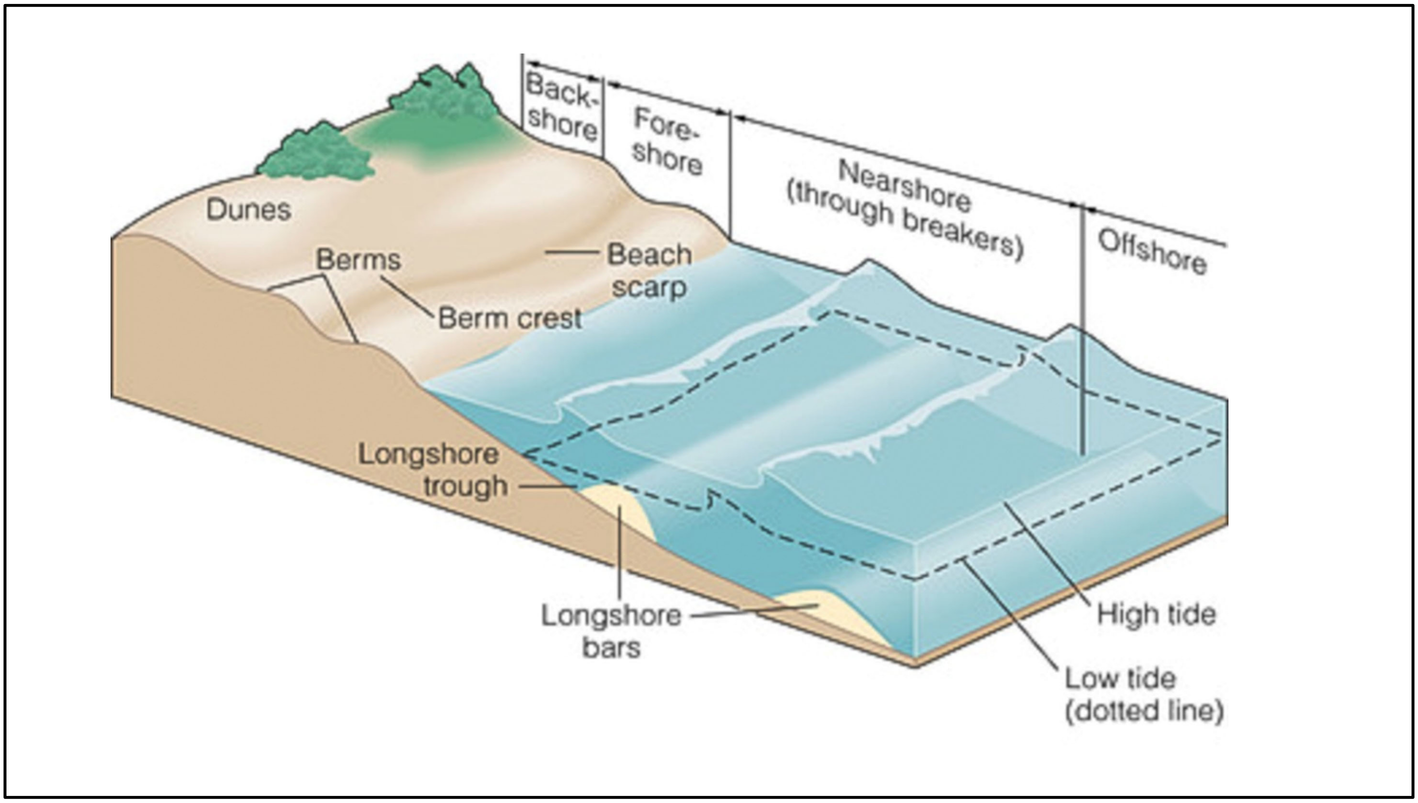
Summer wave regime beach in La Jolla, CA


Micky Ngyen/NPS
Summer Beach
Laura Castellini/NPS
Winter Beach


Summer profile
Winter profile

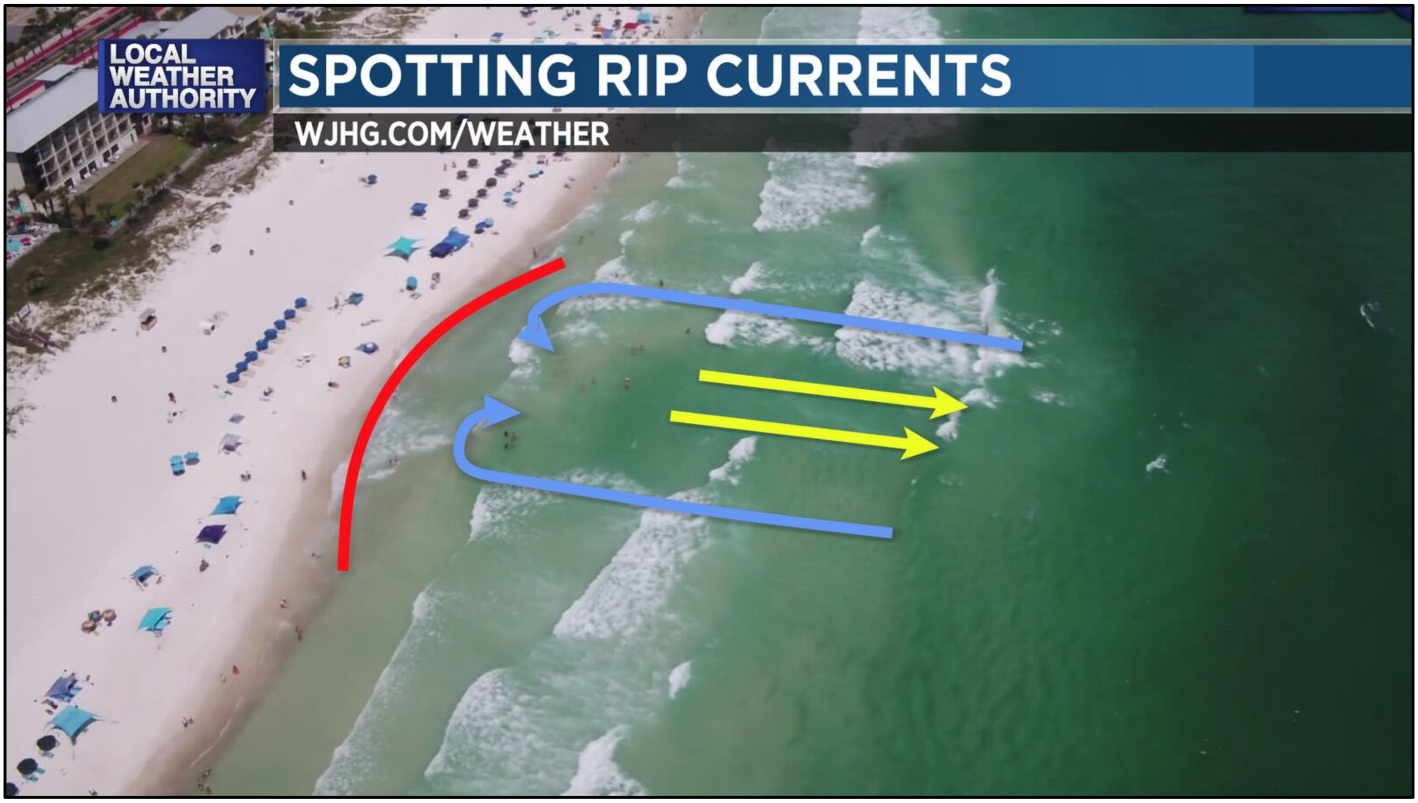
Two sandbars with a trough between them in Panama City Beach.

https://www.newsherald.com/story/news/environment/2018/06/17/tale-of-two-sandbars-pcb-coastline-somewhat-unusual/11953252007/

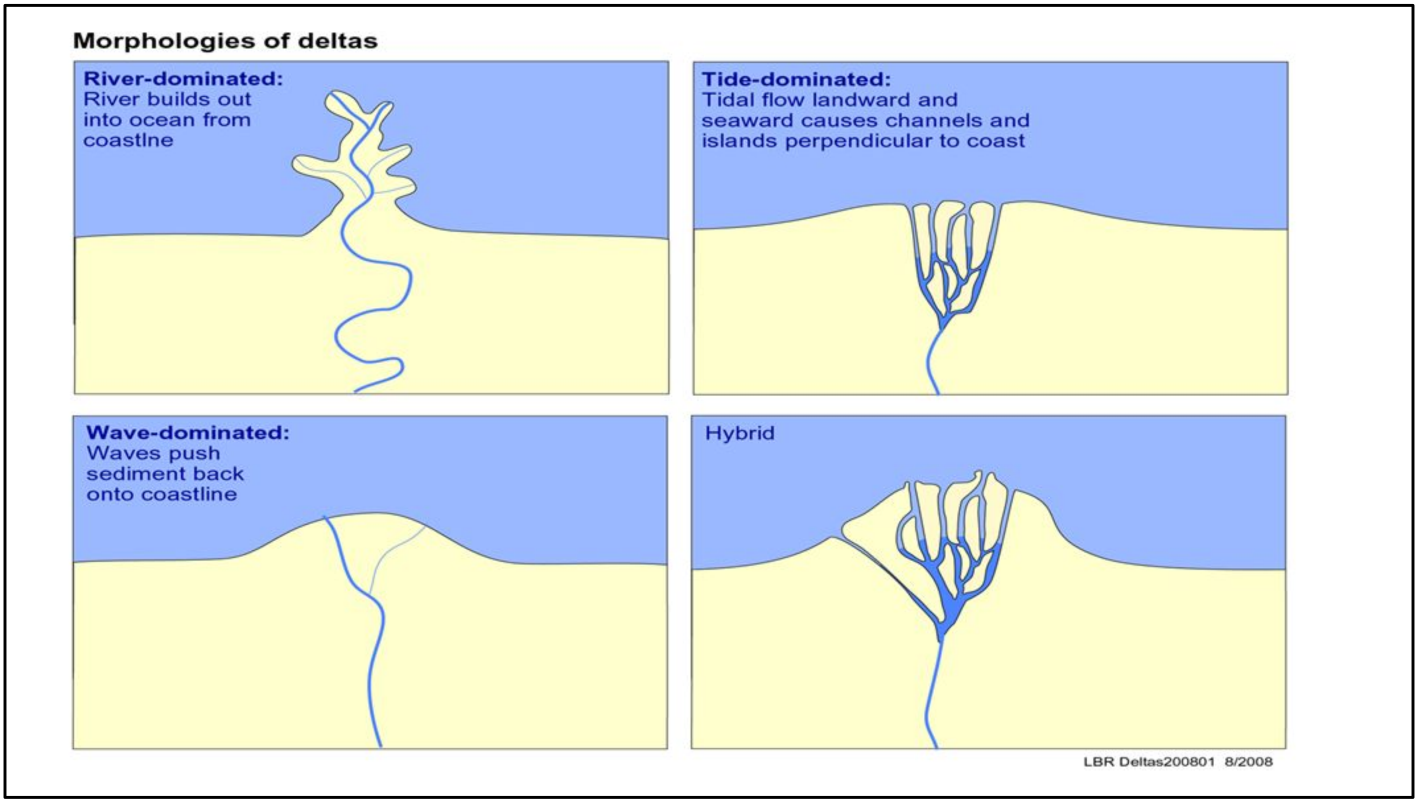


Sandy beach features

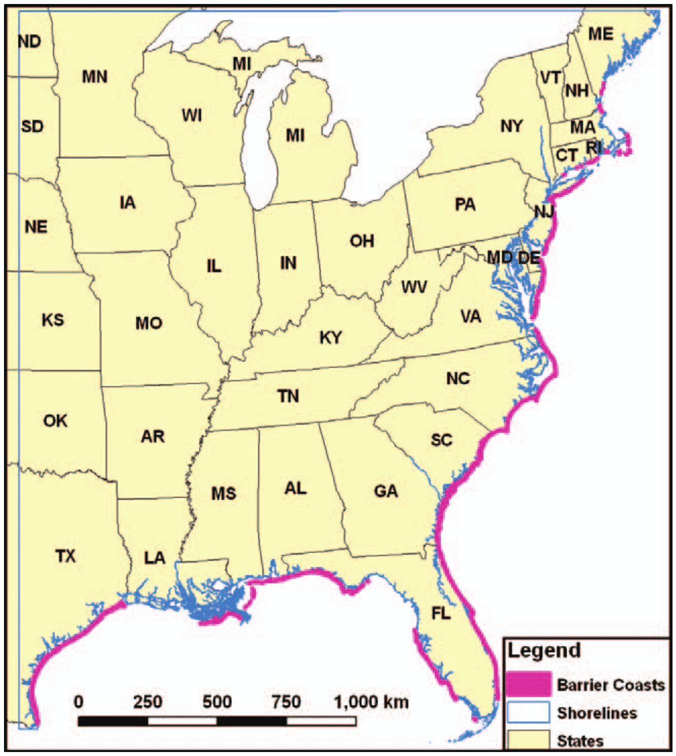
Panama City Beach from St Andrews St Park pier


LOCAL WEATHER AUTHORITY
SPOTTING RIP CURRENTS
WJHG.COM/WEATHER

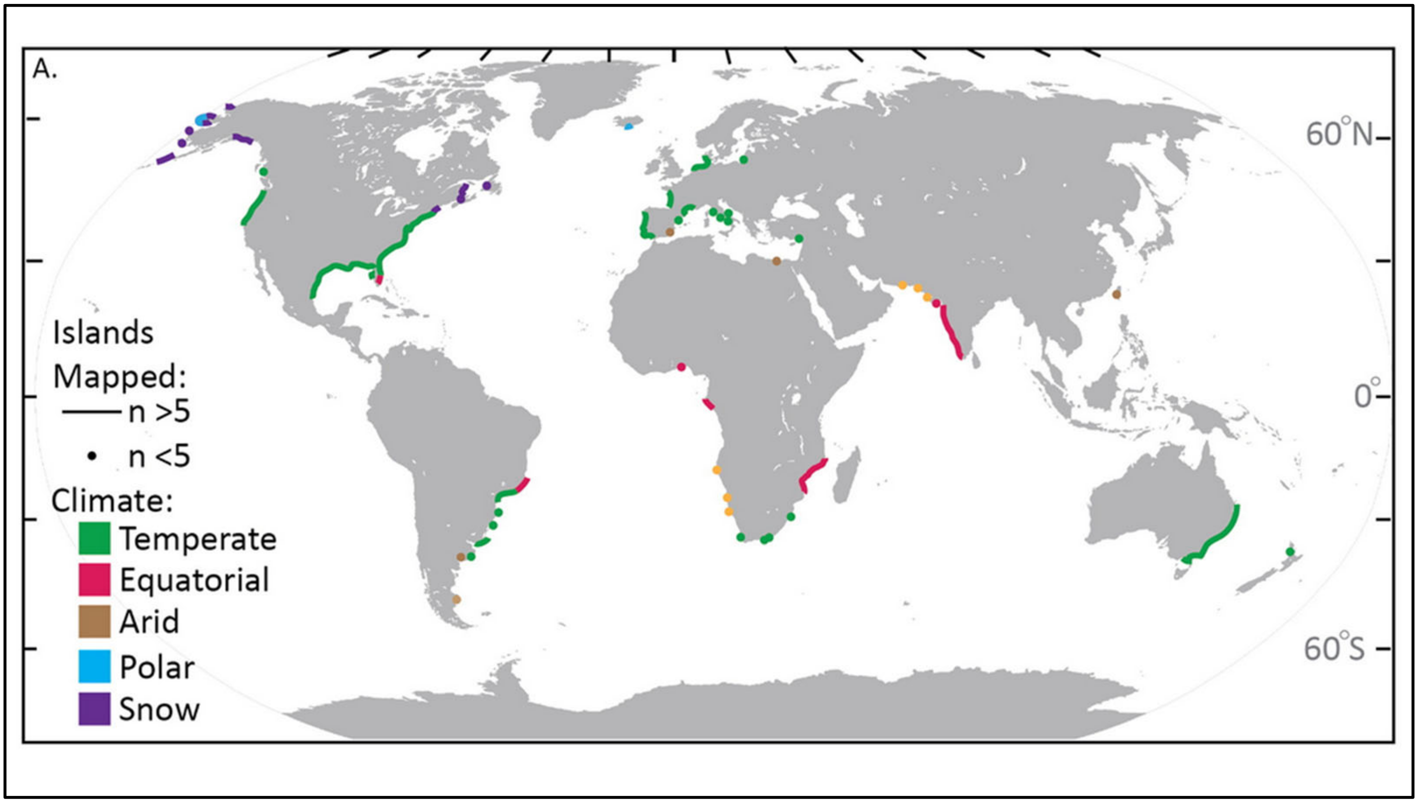
Rip currents

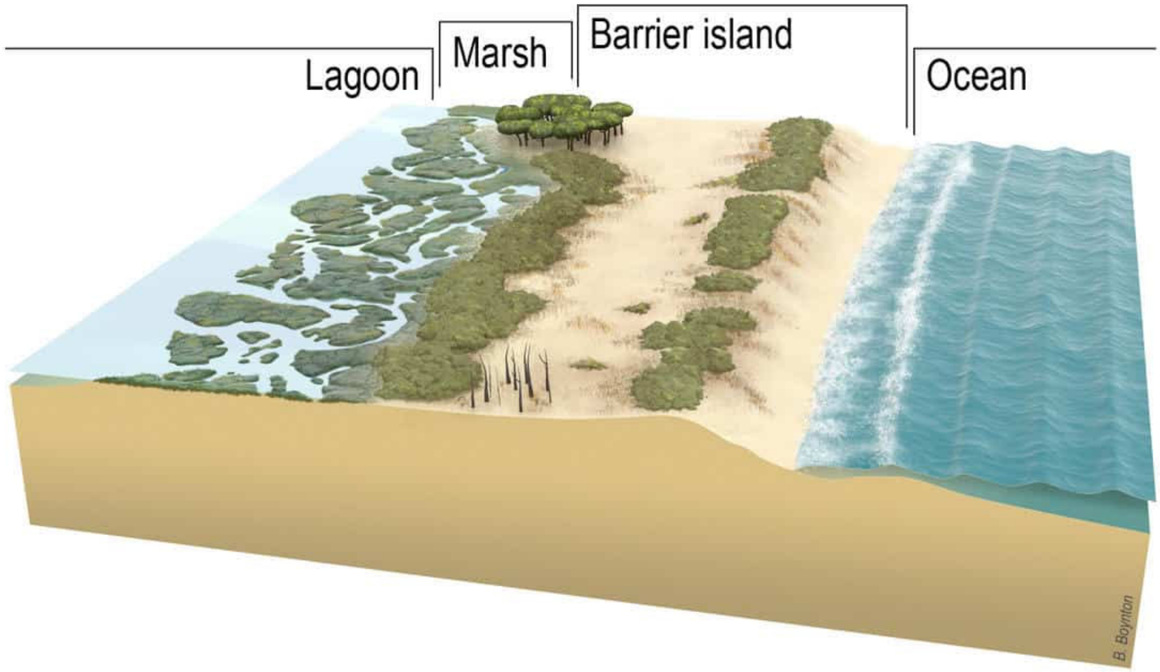

Morphologies of deltas
River-dominated:
River builds out into ocean from coastlne
Tide-dominated:
Tidal flow landward and seaward causes channels and islands perpendicular to coast
Wave-dominated:
Waves push sediment back onto coastline
Hybrid
LBR Deltas200801 8/2008

Delta types

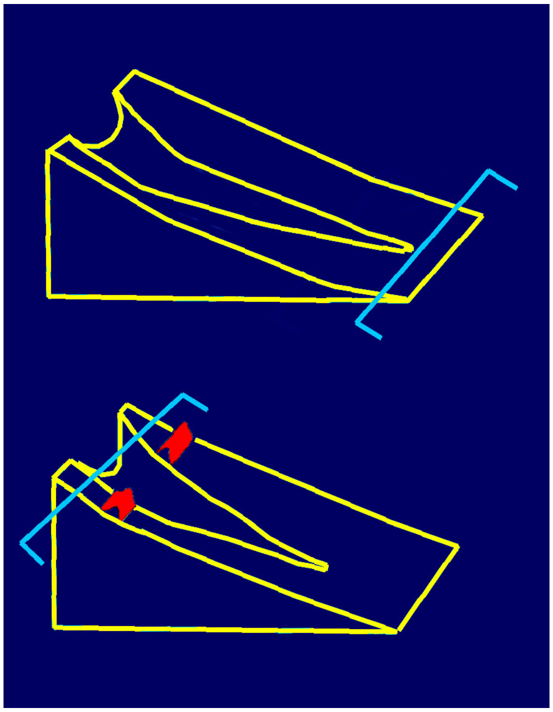


Barrier island coasts


A.
60°N
0°
60°S
Islands
Mapped:
n >5
n <5
Climate:
Temperate
Equatorial
Arid
Polar
Snow


Lagoon
Marsh
Barrier island
Ocean
B. Boynton

Deltas can have well-developed estuarine habitat, salt marsh and tidal creek networks depending upon the delta type. Tidal deltas typically have the best developed estuarine systems with salt marsh and tidal creeks.



Barrier island formation

- Start with lowered sea levels
- Location along gradually sloping coastal plain coast adjacent to a river
- Rising sea levels
- Drowning of former river valley
- Exposure and erosion of valley headlands to wave energy
- Wave energy is sufficient to erode and transport sand
- Nearshore deposits of sediment form
- Vegetation stabilizes sediment
- If sediment remains abundant, dune building can occur and create more permanent island

Their formation is a complex interplay of geological, oceanographic, and biological processes, often shaped over millennia. The process begins with the presence of river valleys, a sea-level lowstand, followed by a rise in sea level, erosion of headlands, and the stabilization of sediments by vegetation.

The initial stage in the formation of barrier islands involves the creation of river valleys during a period of sea-level lowstand. During these periods, sea levels are much lower than they are today, typically due to extensive glaciation. Rivers flowing from inland areas cut deeply into the landscape, forming valleys that extend across the continental shelf. These valleys serve as the foundational framework for the future development of barrier islands.

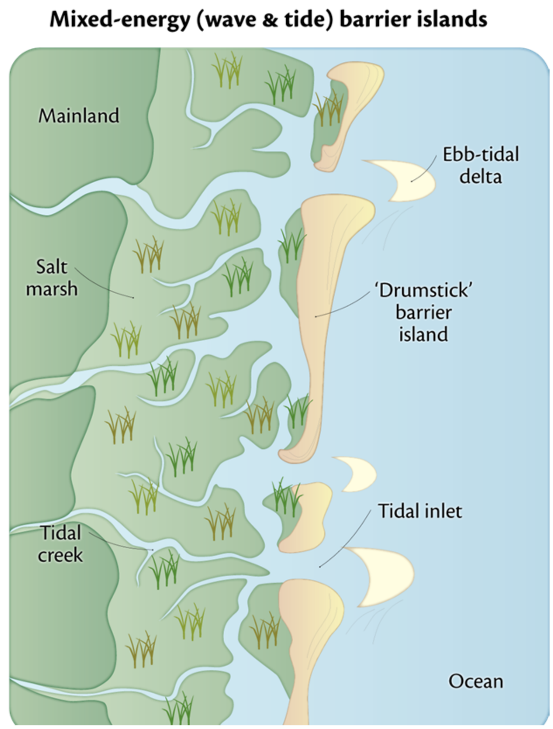
As the climate warms and glaciers retreat, global sea levels rise. This phenomenon, often associated with interglacial periods, leads to the inundation of the previously exposed continental shelf and the flooding of river valleys. The rising waters push sediment from rivers and offshore sources into shallow coastal environments, creating conditions ripe for the emergence of barrier islands.

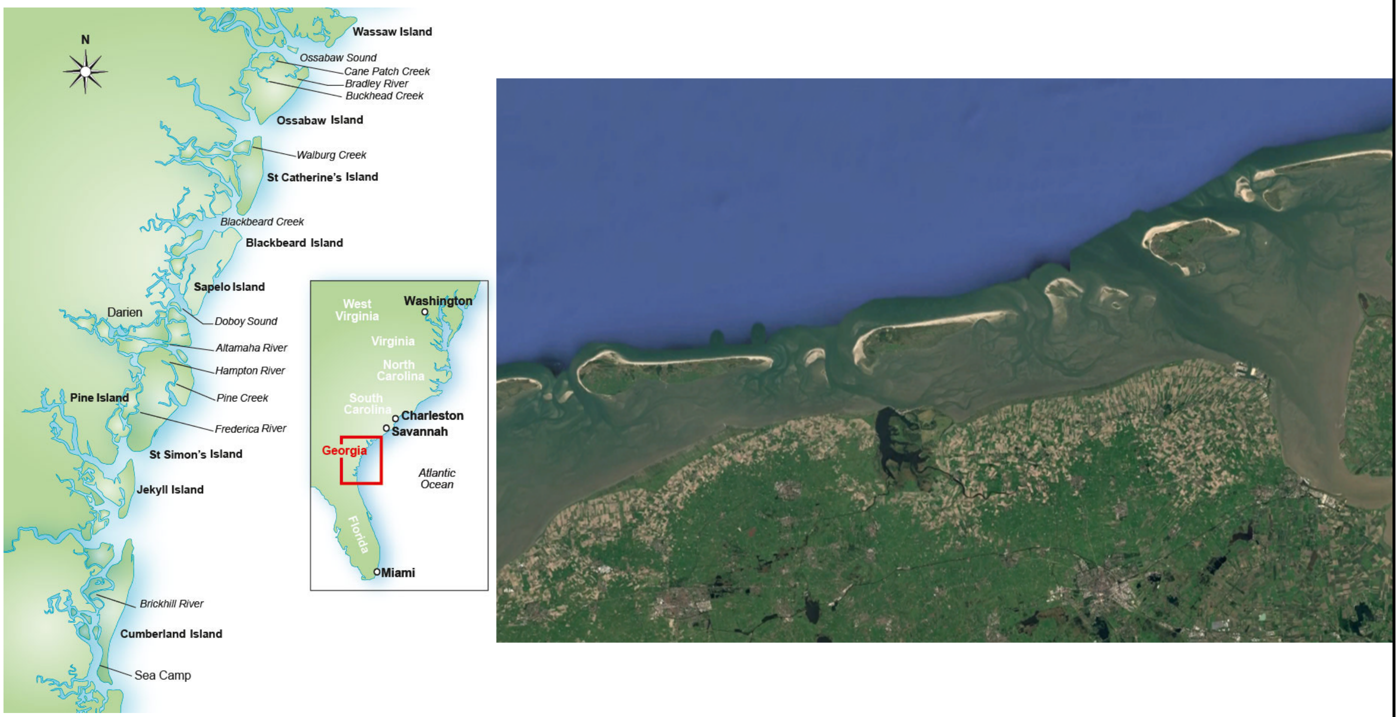
The next critical step in barrier island formation is the erosion of exposed headlands. As waves and currents interact with the coastline, they erode material from the headlands and transport sediments alongshore. These sediments accumulate in regions where wave energy diminishes, often in the vicinity of flooded river valleys. Over time, the buildup of these sediments creates sandbars and other depositional features, which are precursors to barrier islands.

The final phase in the formation of barrier islands involves the stabilization of sediments by vegetation. Plants such as grasses and shrubs play a crucial role in anchoring the loose sands that compose these islands. Vegetation not only traps and stabilizes sediments but also helps to build up the island's elevation by reducing wind and water erosion. This biological component ensures the long-term persistence and growth of barrier islands in dynamic coastal environments.

Mixed energy barrier island

- Low wave energy and high tidal range
- Islands are wide and not very long
- Separated by tidal inlets
- Storm surges are directed into tidal inlets by ridge and swale topography on island
- Network of tidal creeks in salt marsh absorb storm surges





Barrier islands of the northern coast of the Netherlands (right) and the Georgia coast (left)

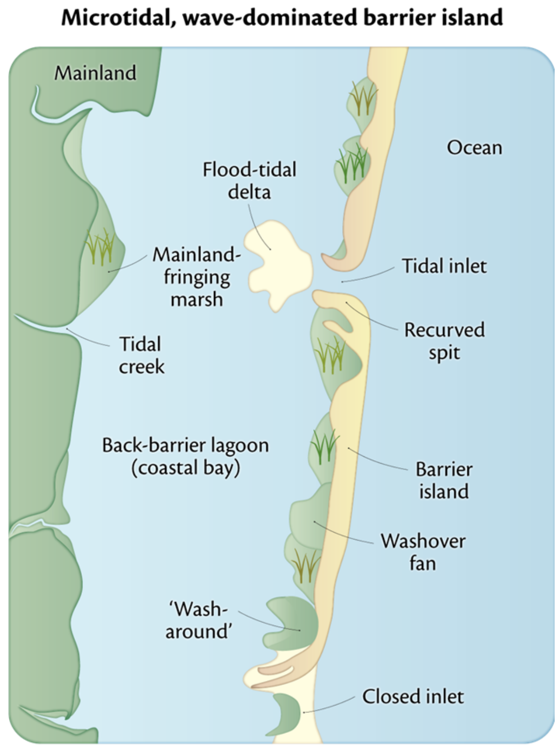
Ridge and swale topography on Sapelo Island, a mixed energy barrier island. These form during periods when the coast is depositional and accreting seaward.

Ridge and swale topography on Sapelo Island, a mixed energy barrier island

Ridge and swale topography on Sapelo Island, a mixed energy barrier island

Wave-dominated barrier island

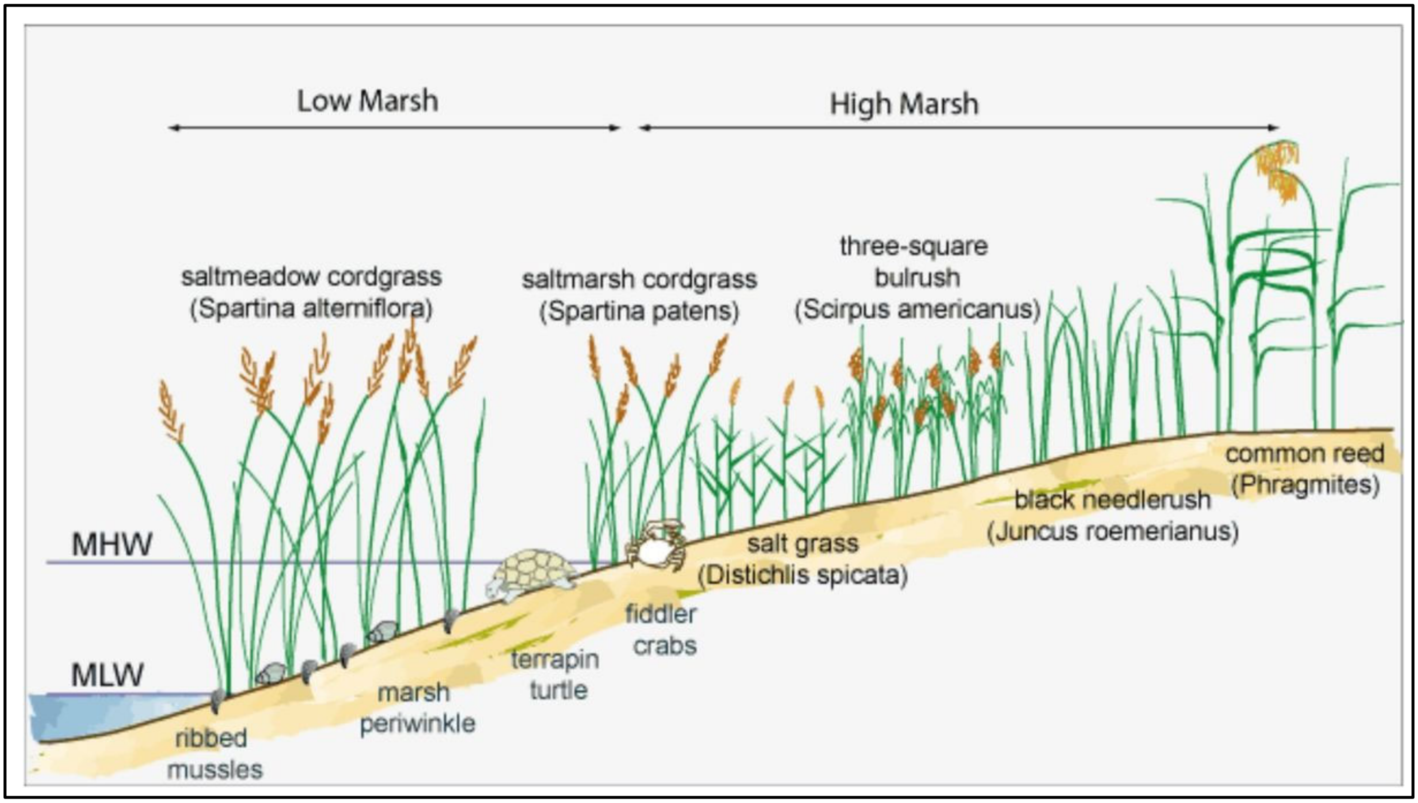
- High wave energy and low tidal energy
- Barrier islands are long and narrow
- Often have large back-barrier lagoons
- Storm surge and sediments flow over island in a processes know as overwash

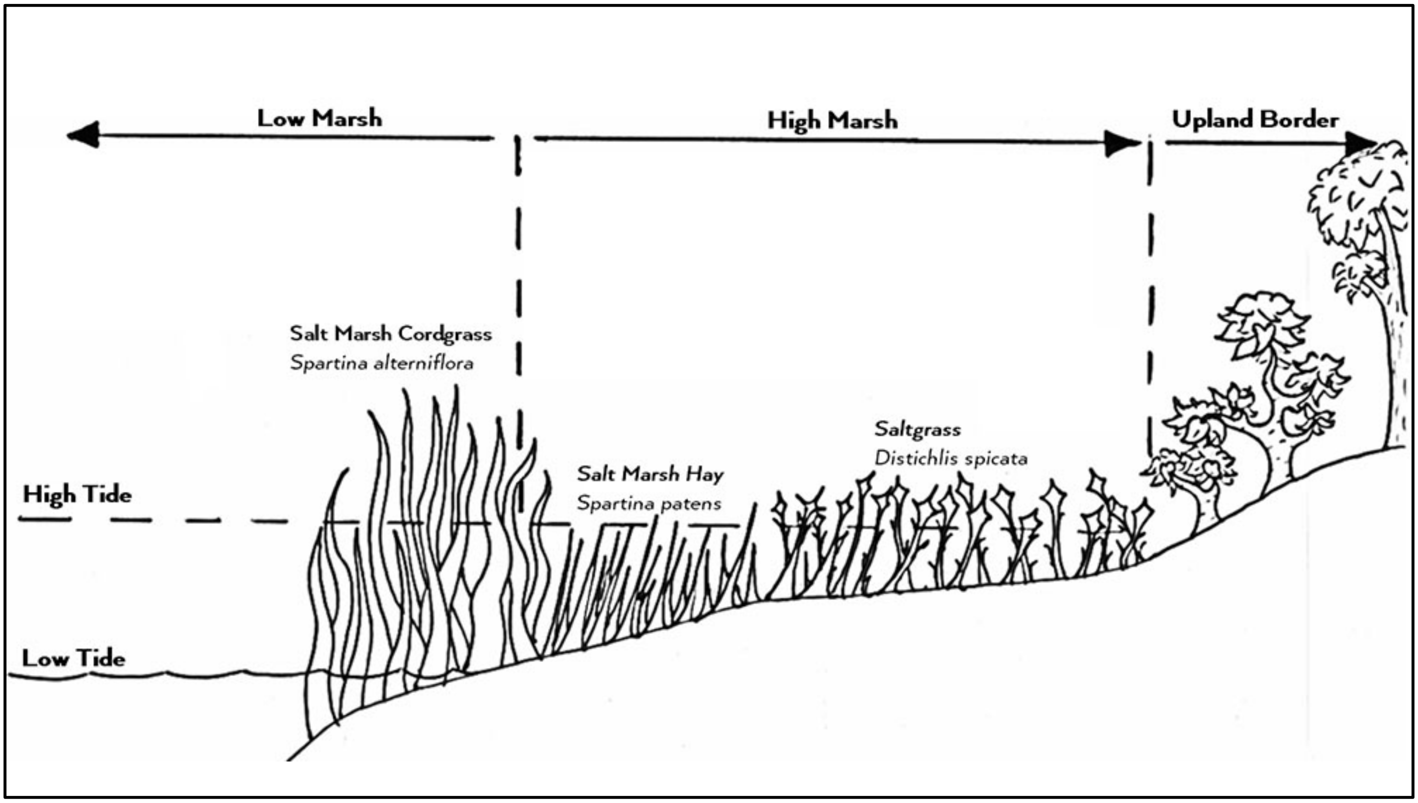


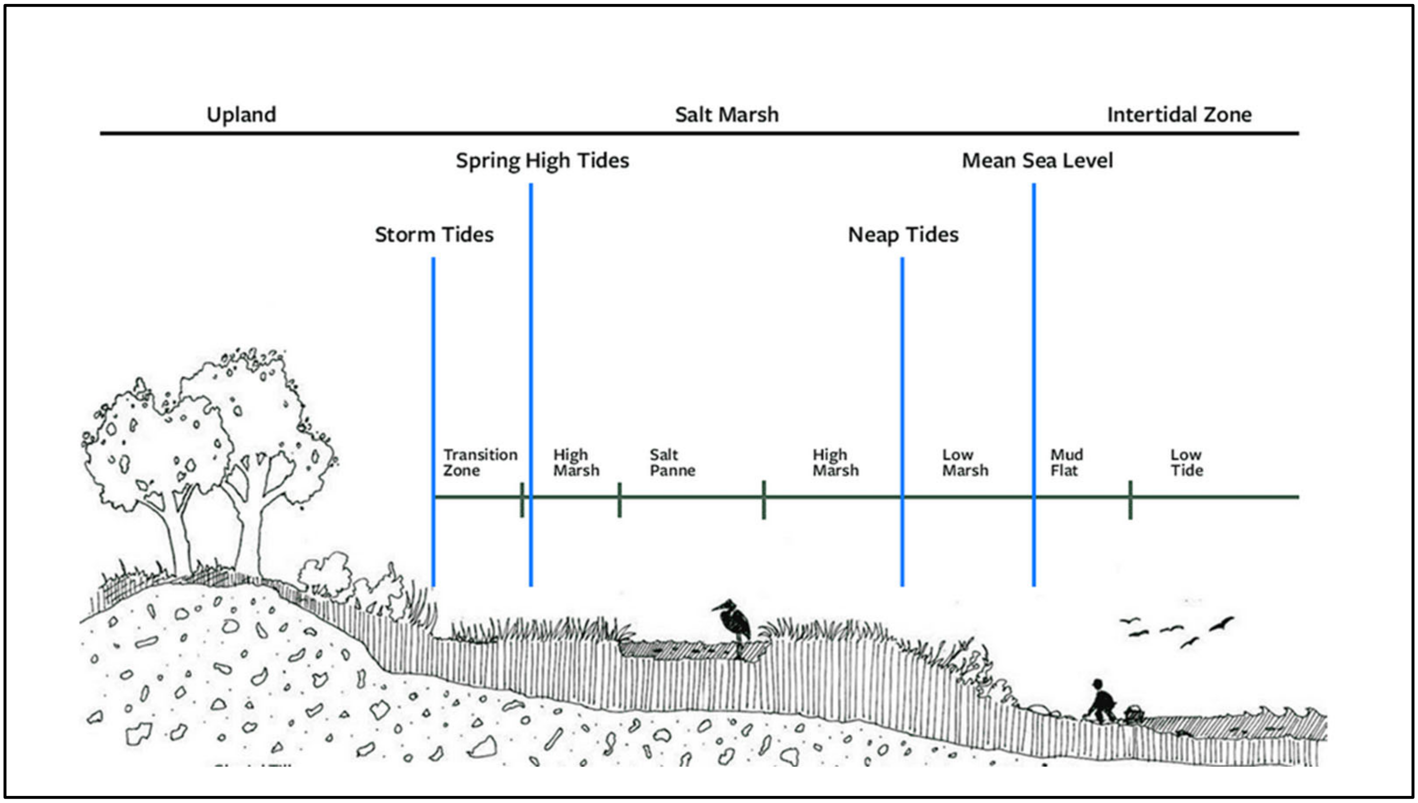
Overwash on Shackelford Banks in the Outer Banks

68

Barrier island can migrate inland with sea level rise. Overwash (above) during storms deposits sediment landward allowing an island to retreat landward intact. However, if rate of sea level rise is rapid, island can't rollover backward fast enough and they drown in place

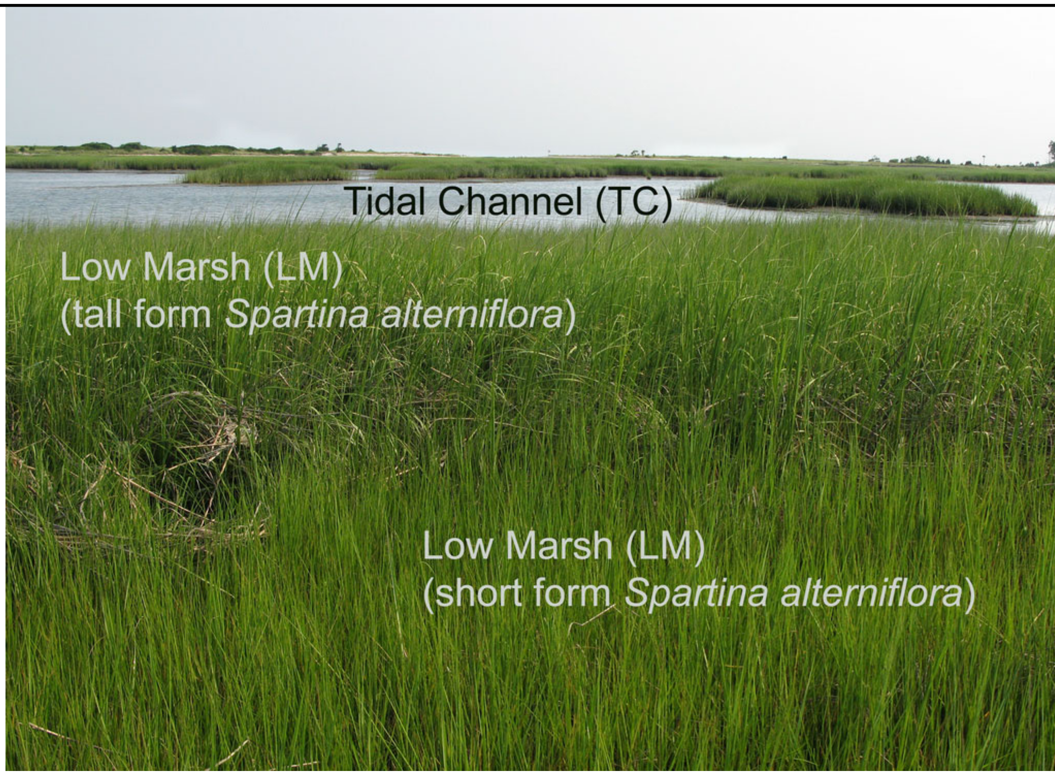

Low Marsh
High Marsh
saltmeadow cordgrass
(Spartina alterniflora)
saltmarsh cordgrass
(Spartina patens)
three-square
bulrush
(Scirpus americanus)
common reed
(Phragmites)
black needlerush
(Juncus roemerianus)
salt grass
(Distichlis spicata)
MHW
MLW
fiddler
crabs
terrapin
turtle
marsh
periwinkle
ribbed
mussles


Low Marsh
High Marsh
Upland Border
Salt Marsh Cordgrass
Spartina alterniflora
Salt Marsh Hay
Spartina patens
Saltgrass
Distichlis spicata
High Tide
Low Tide


Upland
Salt Marsh
Intertidal Zone
Spring High Tides
Mean Sea Level
Storm Tides
Neap Tides
Transition Zone
High Marsh
Salt Panne
High Marsh
Low Marsh
Mud Flat
Low Tide


Juncus geradii
Spartina patens
Spartina alterniflora zone

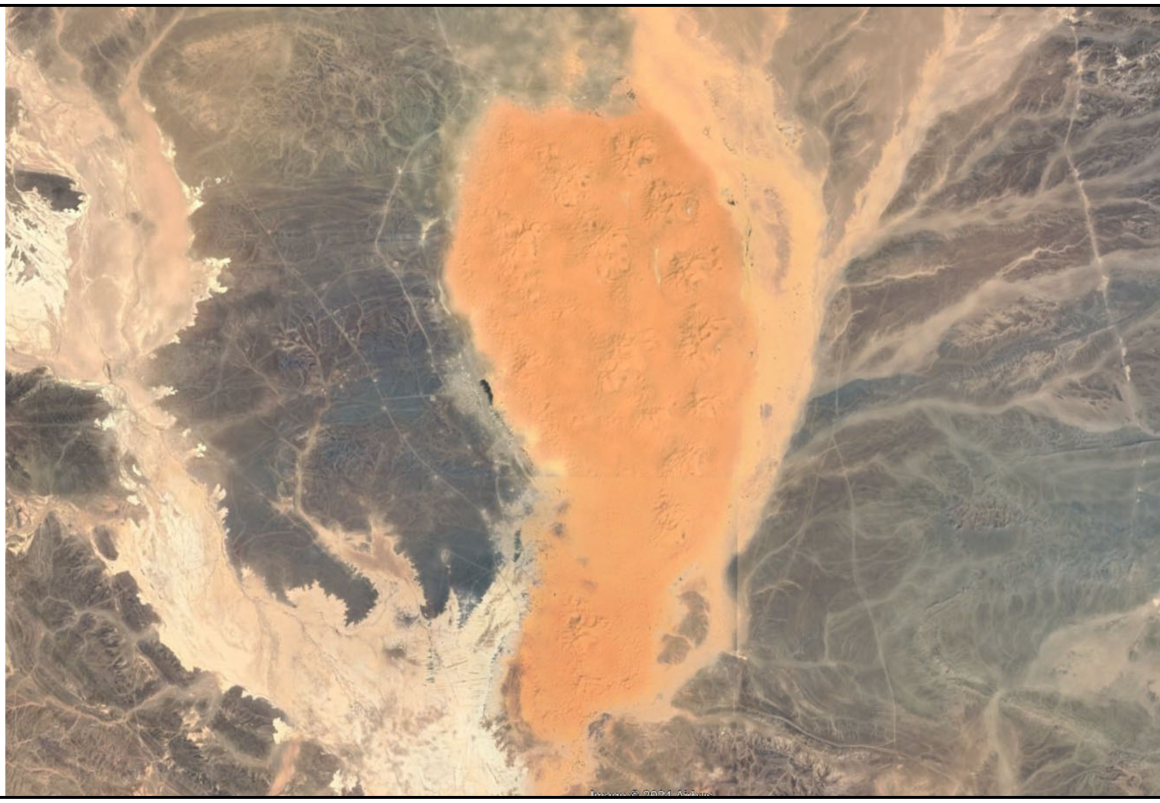

High marsh
Low marsh


Tidal Channel (TC)
Low Marsh (LM)
(tall form *Spartina alterniflora*)
Low Marsh (LM)
(short form *Spartina alterniflora*)

Dune types

- Free dunes: independent of vegetation and are shaped primarily by the wind; highly mobile, shifting according to prevailing wind patterns. Often found in desert regions where vegetation is sparse, and sand can move freely. Can also occur in some coastal areas
- Anchored dunes: movement restricted by local topography or vegetation, often forming along oceans, near lakes, or in regions with partial vegetation that limits their migration. Dunes at the coast are often referred to as foredunes. Vegetation can anchor dunes where climatic conditions allow the plants to establish and grow.

Erg Chebbi in the Sahara Desert



Erg Chebbi, northwestern Africa

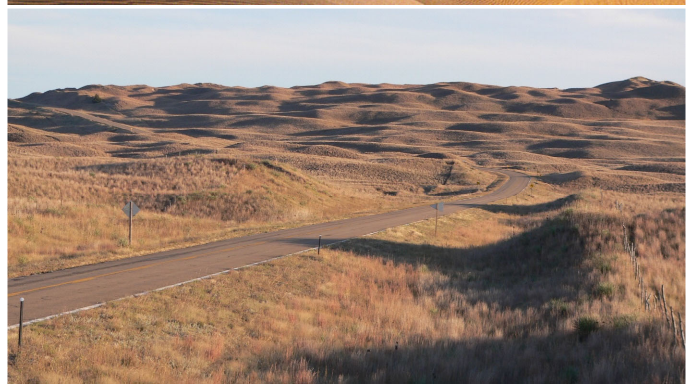
Ergs versus deserts

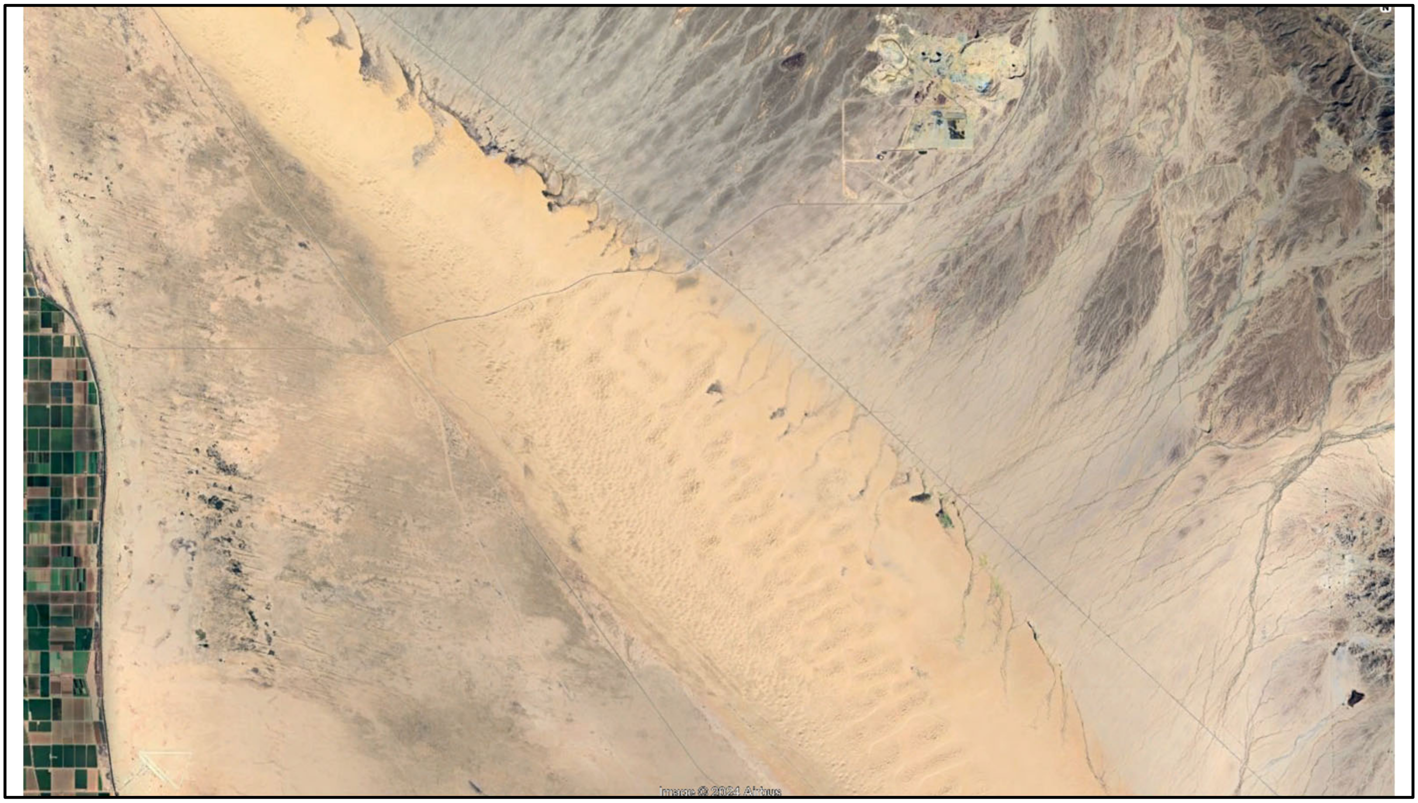
- Deserts can be hot or cold and include many different landforms – mountains, dunes, even ice in polar 'deserts', as well as different types of vegetation and soils
- Desert is more of a climatic designation .
- Hot desert: Chihuahuan Desert of northern Mexico
- Midlatitude desert: Great Basin Desert of Nevada

Great Basin Desert of Nevada, top
Chihuahuan Desert, bottom

The concept of a polar desert is well-supported in scientific literature and is widely recognized as a valid climatological classification. Polar deserts are extremely cold, dry areas located in polar regions, primarily in parts of Antarctica and the high Arctic. They are characterized by low annual precipitation (often less than 250 millimeters per year, similar to hot deserts) and extreme temperatures.

- Ergs ('sand seas') are more of a geomorphic designation.
- They are landscapes within deserts with expansive sand dunes formed from wind action
- Best developed in hot desert environments, but can occur in cooler climates where geomorphic conditions favor accumulations of large amount of sand
- Can be active as in the Algodones Dunes of southern California (top)
- Or relict as in the Lagoons Sand Hills of Nebraska which initially formed from wind-blow glacial sediments





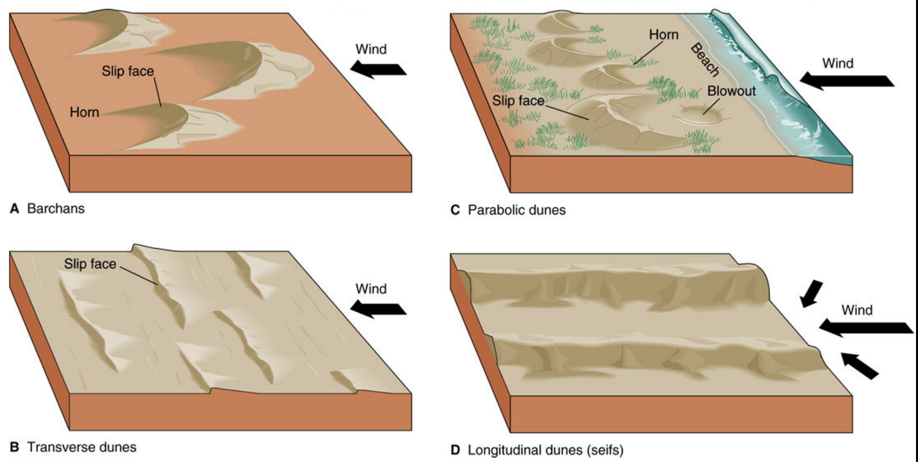
Algodones erg in photo

Other ergs or ‘sand seas’
Rub' al Khali (Empty Quarter) on the Arabian Peninsula is the world's largest continuous erg
The Taklamakan Desert contains extensive sand dunes, with ergs covering significant portions of its area
Simpson Desert, in Australia, this desert features one of the world's largest sand dune systems, with ergs covering vast areas

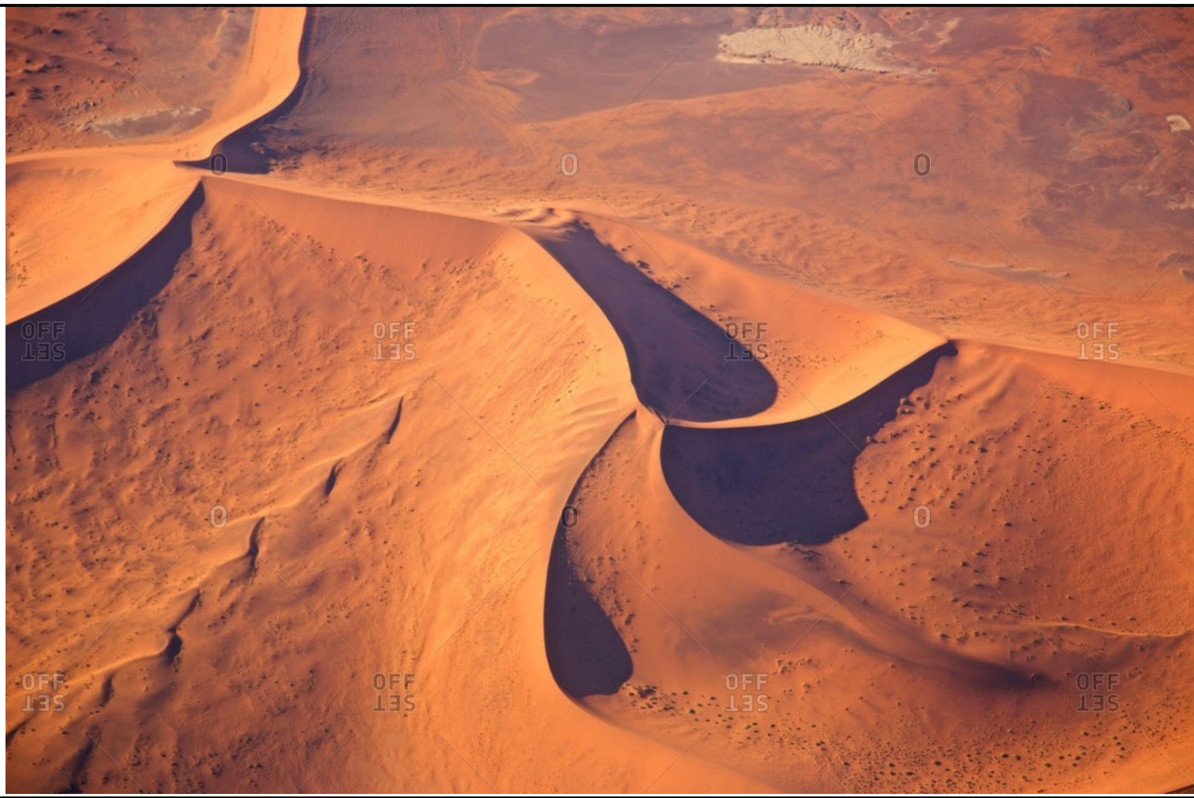
Great Sand Dunes National Park, an erg

Free dune types

- Occur in inland areas and along some arid coastlines
- Types of free dune shaped by predominantly unidirectional winds
  A. Barchans
  B. Transverse
  C. Parabolic – partially stabilized by vegetation
  D. Longitudinal or linear dunes



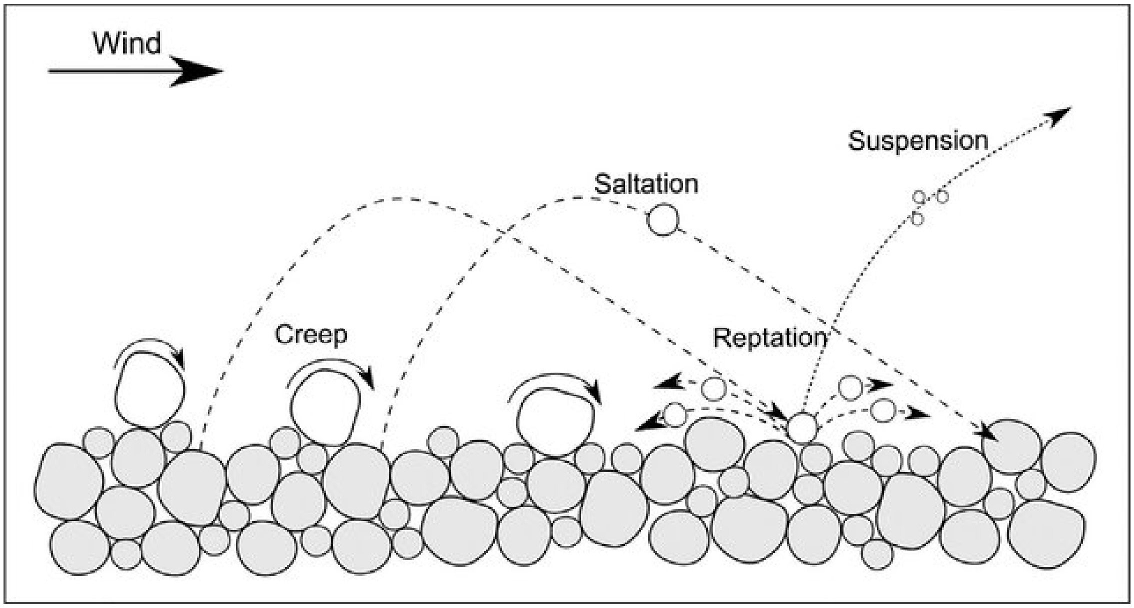
Direction of movement is aligned with prevailing winds



The study focused on the Lala Lallia star dune in eastern Morocco, uncovering its intricate layers and estimating it took about 900 years to form, accumulating sand at a rate of approximately 6,400 metric tons annually. These star dunes, accounting for under 10% of Earth's desert dunes, are the tallest and most impressive, resembling pyramids with arms extending from a central peak.

Star dunes form pyramid-like structure with multiple arms or ridges radiating from a central point, resembling a star. Form in areas with multidirectional or highly variable winds, where no single wind direction dominates. Often found in large desert areas, like the Sahara or parts of the Arabian Desert, where wind patterns shift frequently. Unlike other dunes, star dunes tend to grow in place rather than migrate across the landscape. Their complex structure allows them to build vertically, often making them some of the tallest dunes in desert systems. Star dunes are typically very large and stable, as their structure can withstand shifting winds, allowing sand to accumulate in place over time.

Aeolian erosion

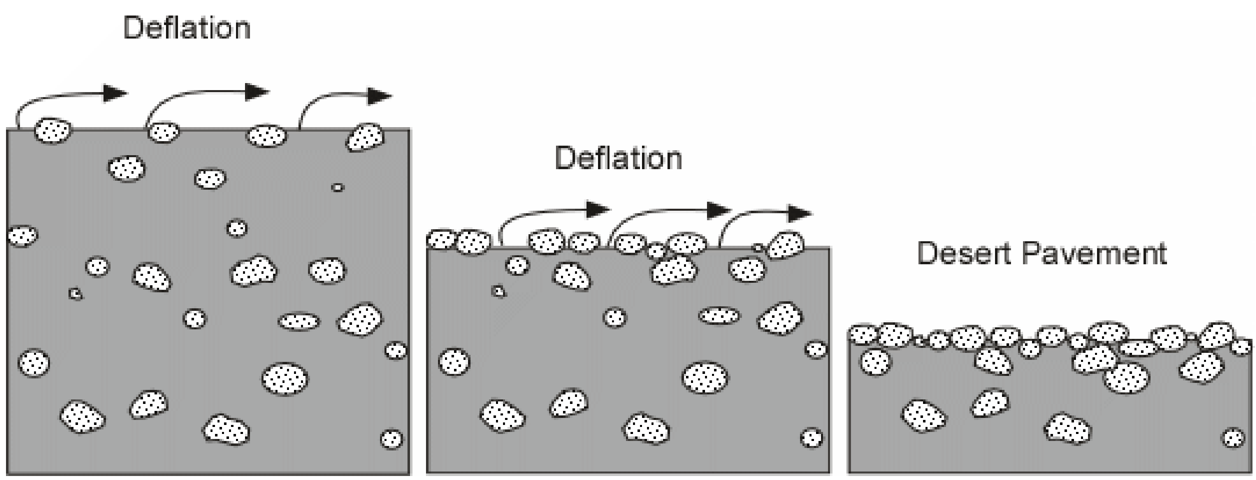


Suspension
Saltation
Reptation
Creep

- Erosional transport is determined by:
  - Size of particles (clay, silt, sand, or larger cobbles)
  - Wind speed
  - Cohesive forces of sediments: for example, clays tend to be more cohesive than sands.

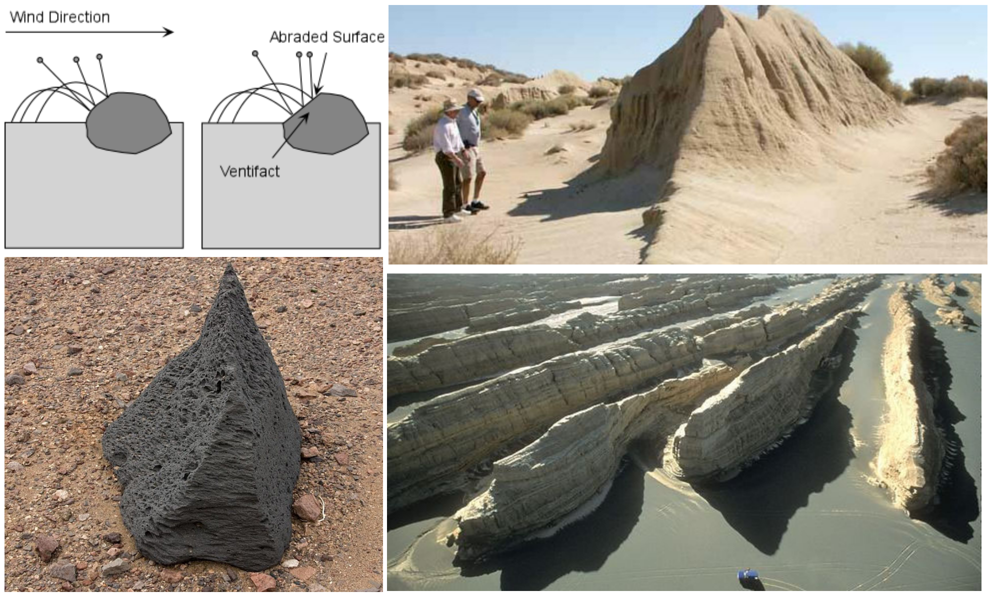
Mojave desert pavement

Deflation and the formation of desert pavements



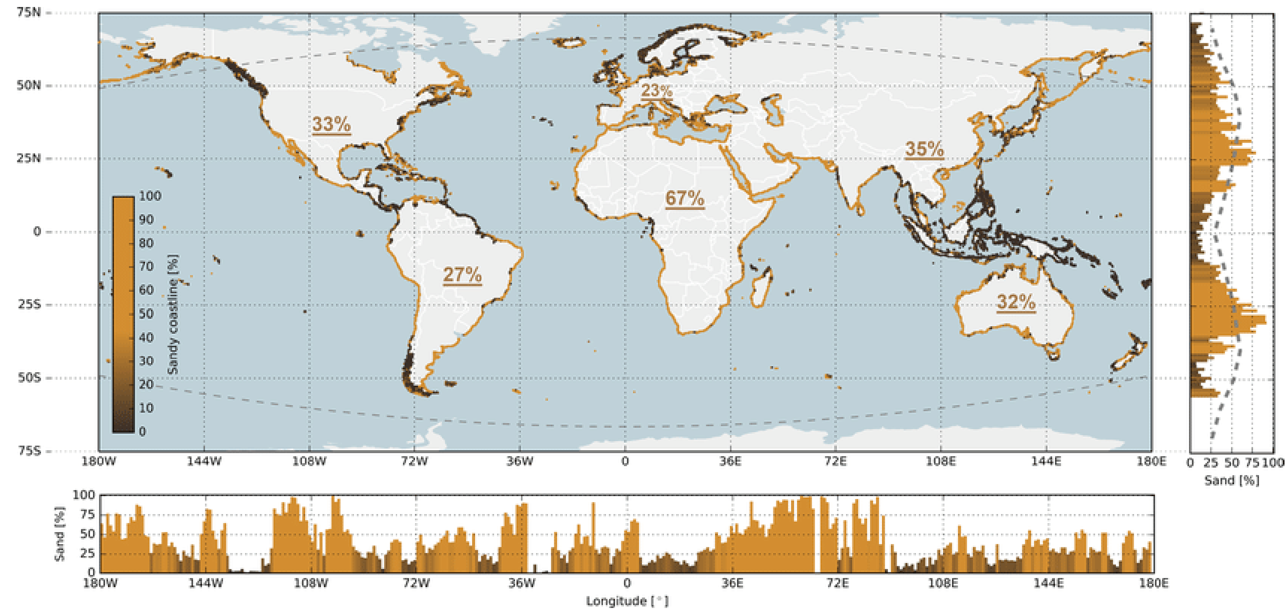
Shell lag in dunes of South Core Banks, NC

Ventifacts and yardangs



Form through abrasion, the grinding of rock surfaces with particles captured in air. Typically well-developed in inland desert regions with a strong prevailing wind

Distribution of coastal foredunes

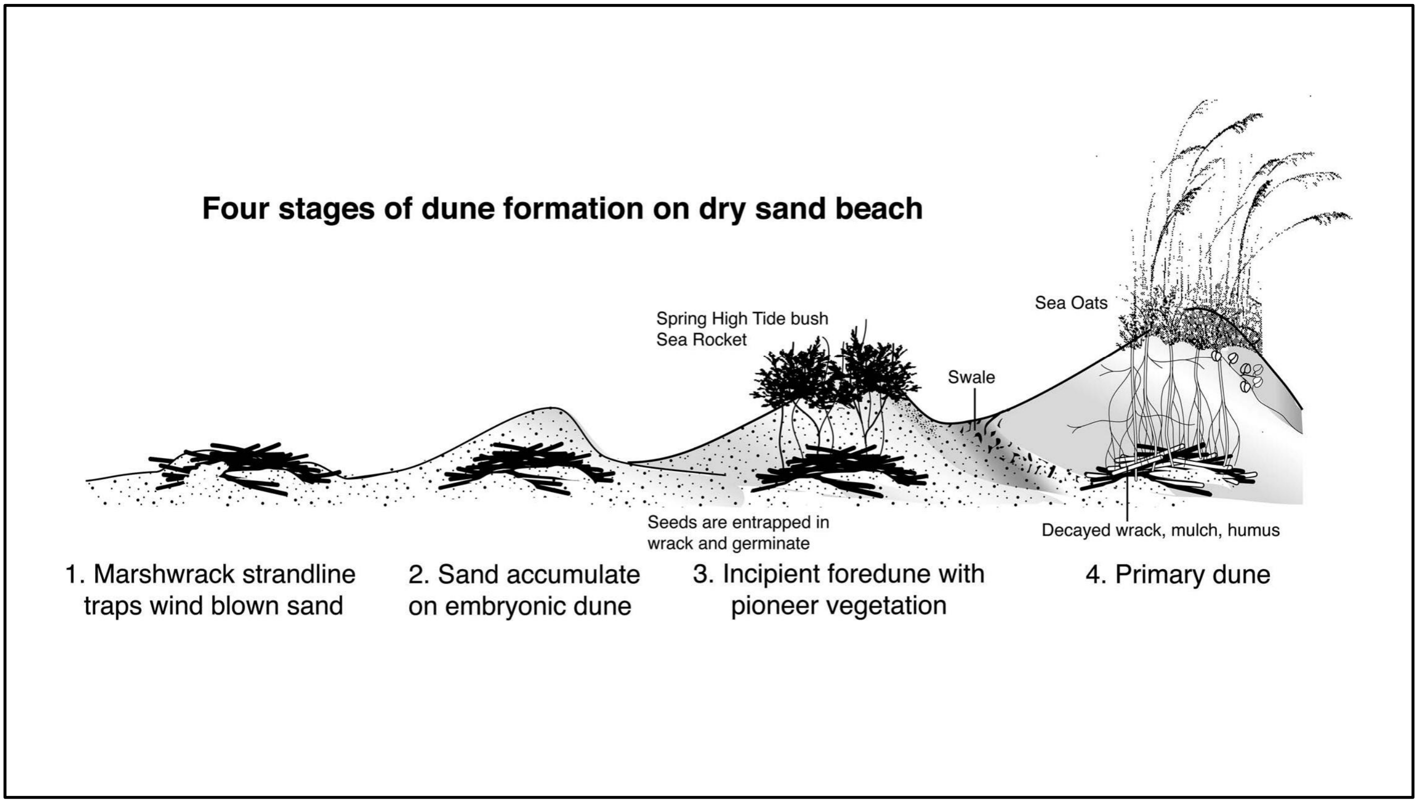


Also found around lakes

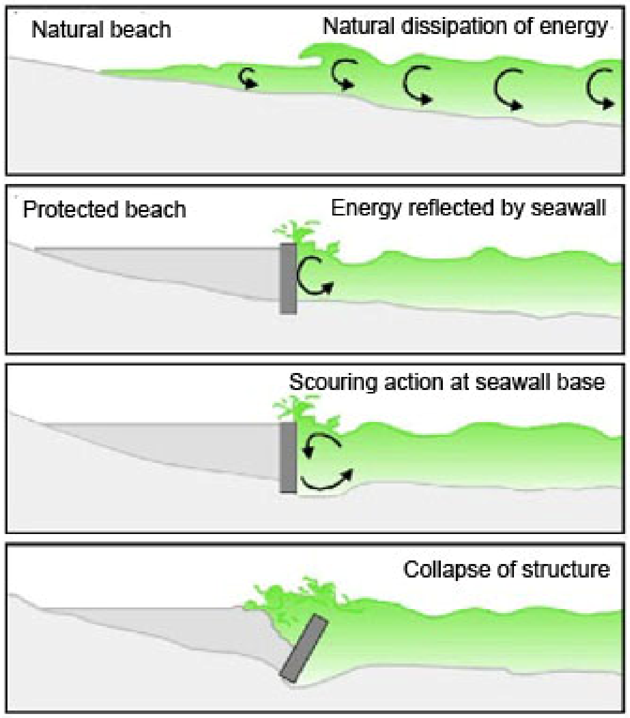
Left (Netherlands), right (Sapelo Island Georgia)

Wrack line and eroded primary foredunes, Sapelo Island

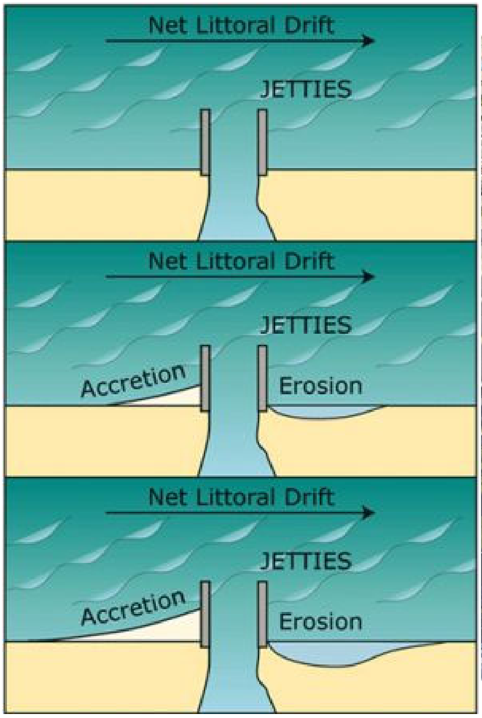
Embryo dunes. In a desert environment these would be called nebkha.

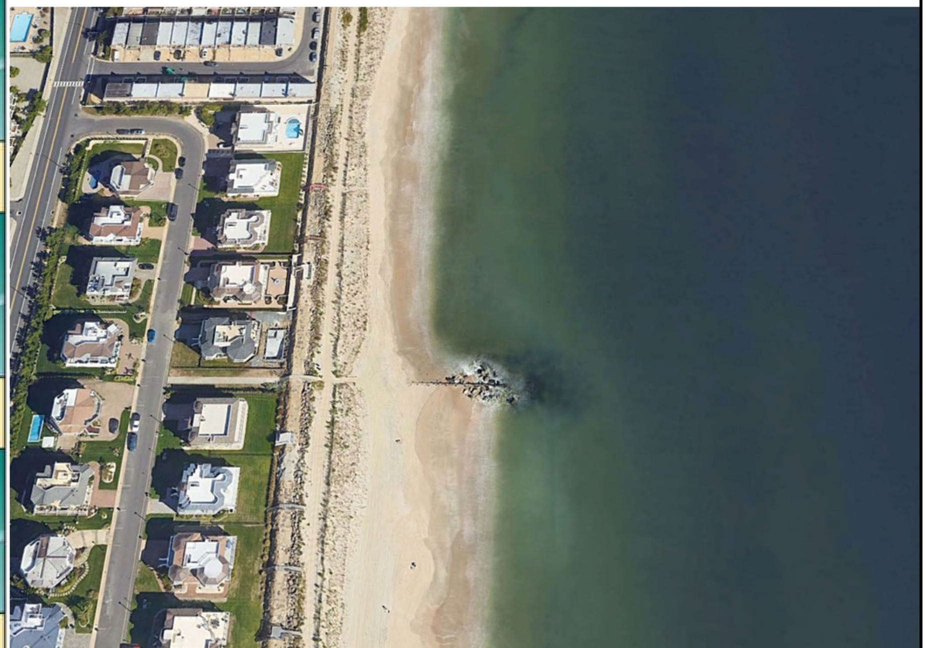

Four stages of dune formation on dry sand beach
Spring High Tide bush
Sea Rocket
Sea Oats
Swale
Seeds are entrapped in wrack and germinate
Decayed wrack, mulch, humus
1. Marshwrack strandline traps wind blown sand
2. Sand accumulate on embryonic dune
3. Incipient foredune with pioneer vegetation
4. Primary dune

Hardening of the shore through sea walls


Natural beach
Natural dissipation of energy
Protected beach
Energy reflected by seawall
Scouring action at seawall base
Collapse of structure

Human-modified sandy coastlines: groins and jetties



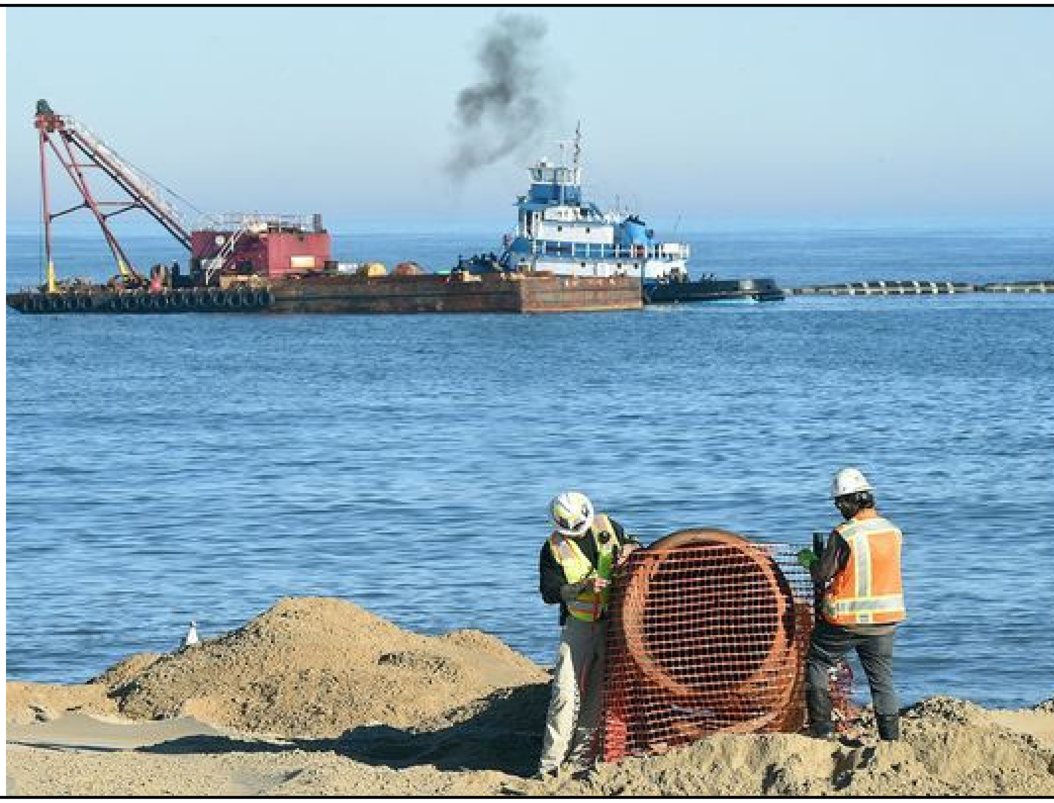


How groins and jetties erode a beach

Bald Head Island, NC

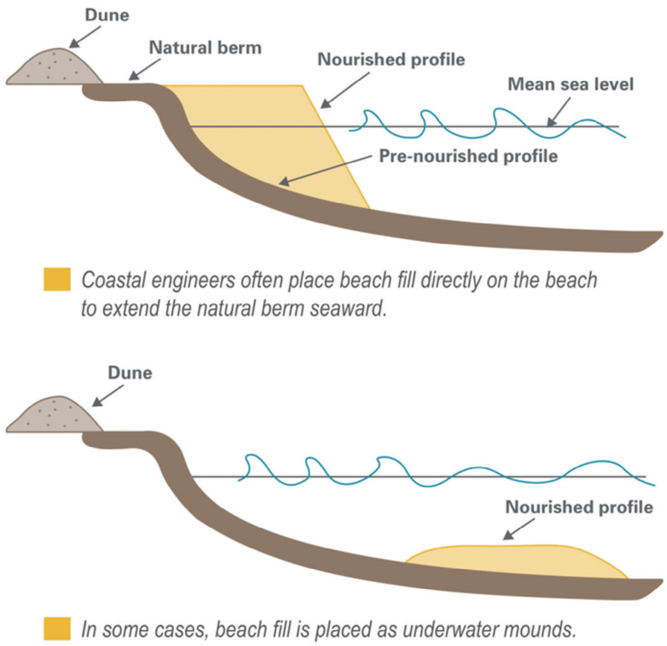
https://coastalreview.org/2024/07/measure-gives-bald-head-island-ok-to-study-adding-groin/

Human-modified sandy coastlines: renourished beaches



Sand is pumped from offshore back onto the beach.

With a few storm events, much of a renourished beach can be washed away. Here, in Panama City, a renourished beach has eroded and left behind a large scarp.



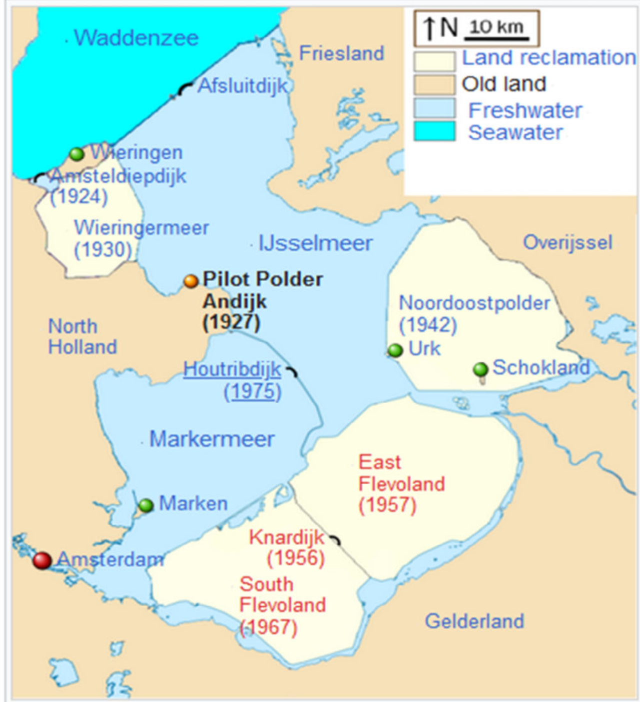
Beach renourishment acts as a temporary solution to beach erosion by adding extra sediment to the shore.

Once the sediment is added, the beach will naturally erode again over time and have to be replenished.

Dune grasses planted to create artificial dune

Land reclamation

- Zuiderzee Works is the name of the land reclamation projects undertaken in the north of Netherland over the past century
- The projects involved the diking of the Zuiderzee, a large, shallow inlet of the North Sea, to form the Ijsselmeer and the Markermeer, which are now freshwater lakes.
- Land was reclaimed from the ocean by the construction of polders.

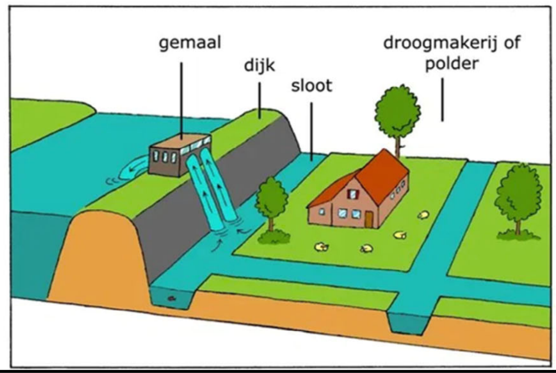


Zuiderzee works

East and West Flavoland, Noordoostpolder, and the polder in the upper left were was once salt water.

Polders

- Polders are a type of landform that results from human actions to reclaim land from the sea or fresh or saltwater wetland areas
- Poldering involves building enclosed dikes in areas covered by water
- Then the water is pumped out of the area contained within these dikes to form a polder



Polders are used around the world