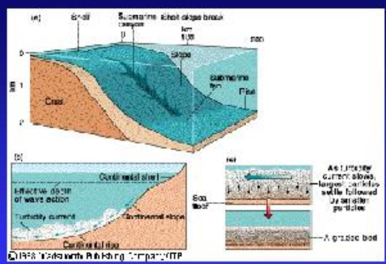
# Coastal Landforms

The coastal zone is that part of the land surface influenced by marine processes. It extends from the landward limit of tides, waves, and wind blown coastal dunes, and seaward to the point at which waves interact significantly with the seabed.

The coastal zone is a dynamic part of the Earth's surface where both marine and atmospheric processes produce rocky coasts, as well as beaches and dunes, barriers and tidal inlets, and shape deltas.

The atmospheric processes include temperature variation, precipitation and winds, while the major marine processes are waves and tides, together with water temperature and salinity. The coast also supports rich ecosystems, including salt marshes, mangroves, seagrass, and coral reefs.

The diverse coastal ecology is favoured by the shallow waters, abundant sunlight, terrestrial and marine nutrients, tidal and wave flushing and a range of habitat types.



Submarine fan

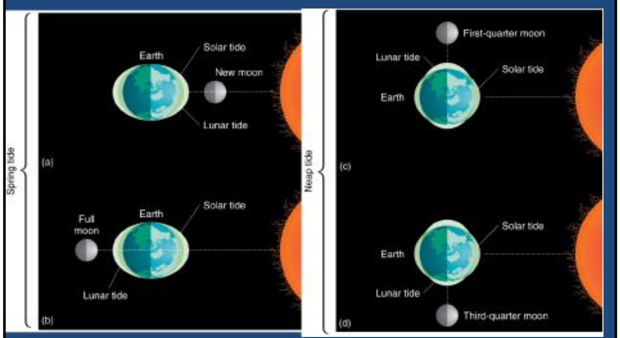
There are three processes active in the Oceans, out of these the following modify the coasts:

Tides

Waves

Currents

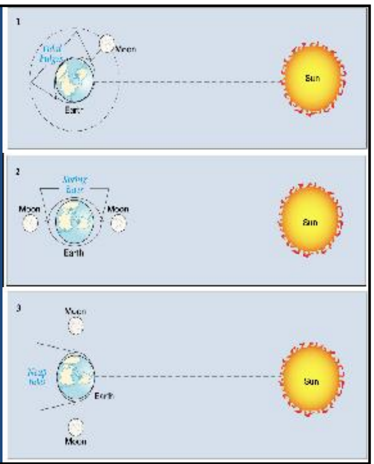
## Tidal forces



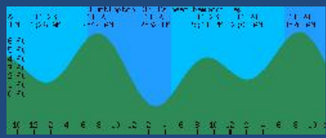

Tides enhanced during full Moon and new Moon
*Sun-Moon-Earth closely aligned*

## Tides

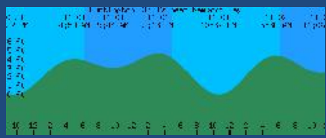
Tide range dependent on relative position of earth, moon, and sun.
Spring Tides - highest tidal range
Neap Tides - lowest tidal range




## Tides

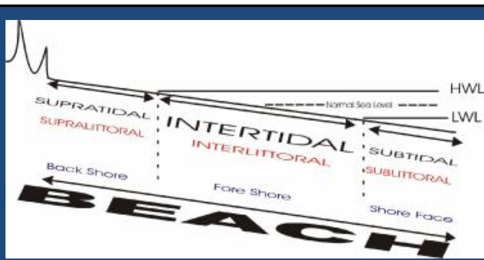


Full Moon

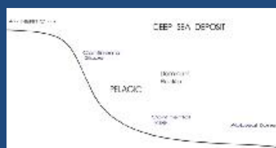


Half Moon

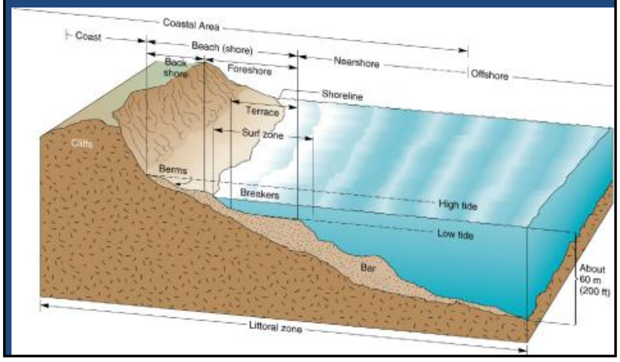
## Tides


| | |
|---|---|
| Neritic : | Low tide to 200m depth |
| PELAGIC | |
| •Planktonic | Floating |
| •Nektonic | Swimmer |
| •Benthic : | Attached/ Burying (Sea Bottom) |




## Littoral Zone




## Basic Concepts

**I. Sea level changes repeatedly**
422 ft. *eustatic* (fluctuations of sea level due to changing capacity of the ocean basins) rise since 18,000 years ago.

- specific landscapes submergent or emergent depending on tectonic change

**II. Waves and resultant currents erode, transport, and deposit sediment load.**

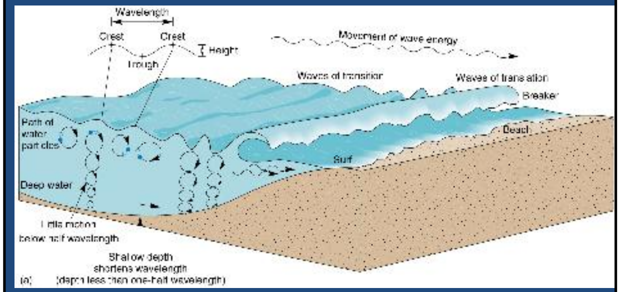
- rocky headlands
- beaches

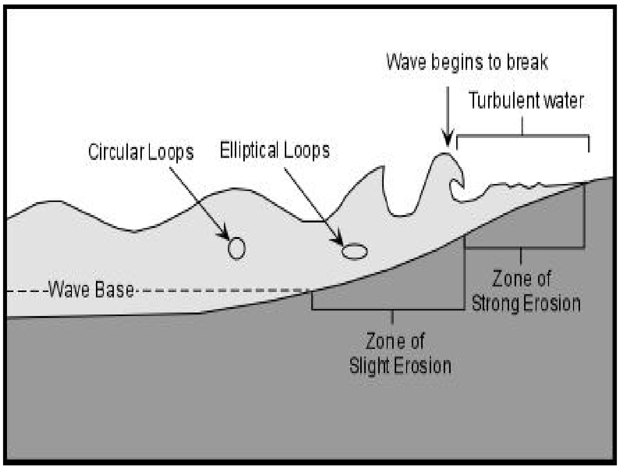
**III. Tides affect all coastal life but have little topographic effect.**

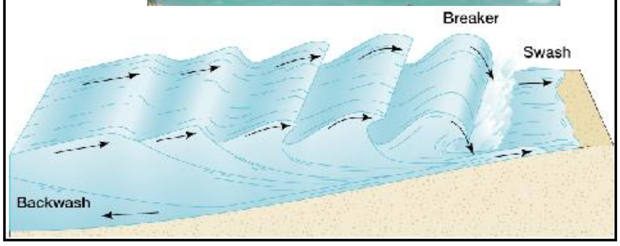
## *Eustatic Changes, Submergent and Emergent Coastlines*

- **During ice ages sea level lowers as more of ocean water is tied up in glaciers.**
- **During interglacial periods sea level rises, flooding many former river valleys creating bays and estuaries.**
- **In areas with rapid tectonic uplift emergent cliffs common and bays rare.**

## Wave Formation




## *Wave Refraction*

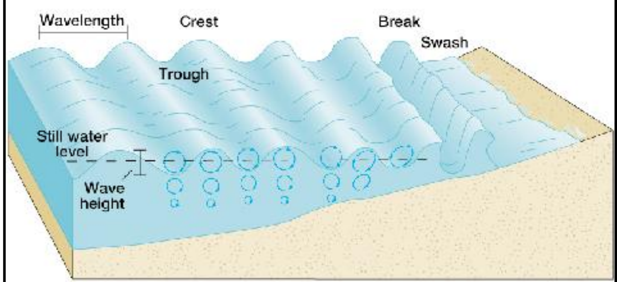
**Straight shoreline**

- drag exerted by the ocean floor causes waves to break parallel with the shoreline.

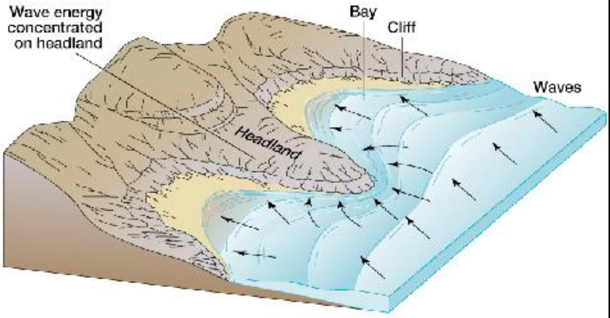
The direction of travel of a wave varies as it approaches an **indented coast**.

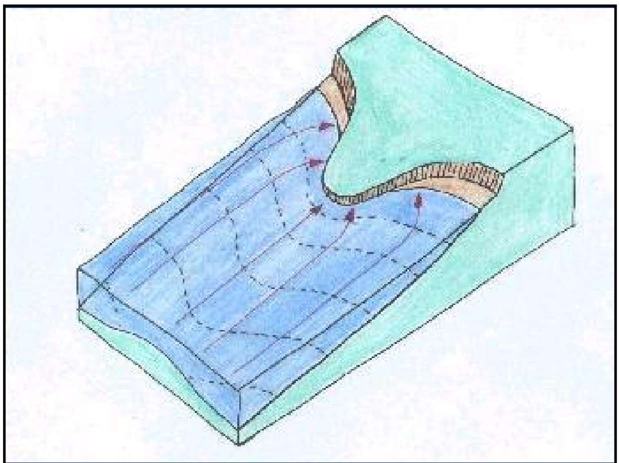
***Crests approaching the headlands experience the drag of the ocean floor first***, which causes:

1. **Increase in wave height**
2. **Decrease in wavelength**
3. **Decrease in velocity**

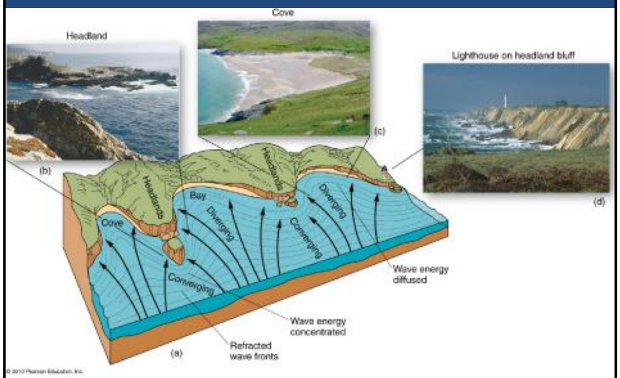


Wave Refraction - waves change directional trend as they approach shore.



## Coastal Straightening




## Coastal Processes and Landforms

- Erosional and depositional landforms of coastal areas are the result of the action of ocean waves.
- <u>Erosional Landforms</u> <u>Depositional landforms</u>

| Erosional Landforms | Depositional landforms |
|---|---|
| Sea Cliffs | Beaches |
| Wave-cut Notches | Barrier Spit |
| Caves | Baymouth Bar |
| Sea stacks | Lagoon |
| Sea arches | Tombolo |

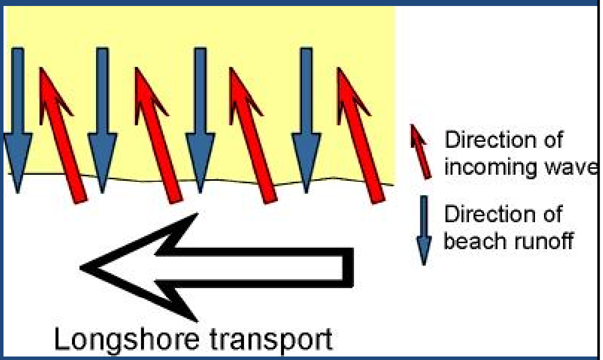
## <u>Erosional Coastal Landforms</u>

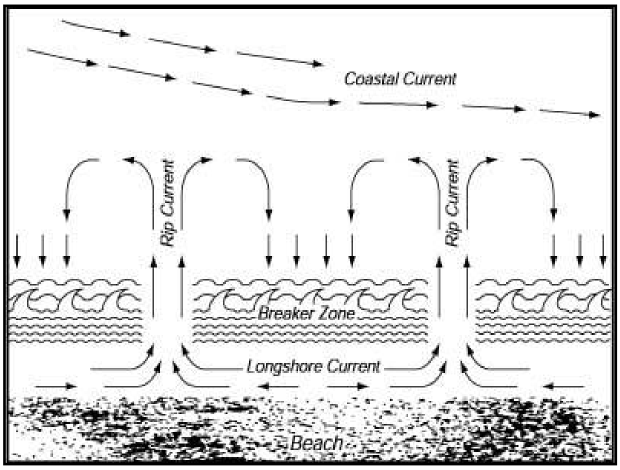
Along rugged, high-relief, tectonically-active coastlines

**Sea cliffs**
A tall, steep rock face, formed by the undercutting action of the sea

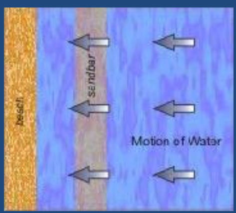
**Wave-cut notches**
A rock recess at the foot of a sea cliff where the energy of waves is concentrated

**Sea Caves**
Caves form in more erosive sediment when the rock does not fully collapse in a deeply-notched environment

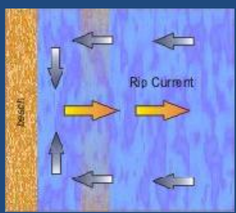



***Rip Currents***




**Rip currents** form when waves are pushed over **sandbars**.




The weight of excess water near the shore can **'rip' an opening in the sandbar**, causing **water to rush seaward.**

Source: NOAA

## Rip Current

Coastal Erosion - dependent on wave size, angle, and frequency. Focused where waves contact coast.

- Headlands, sea cliffs, bluffs, sea stacks, natural bridges
- Beach Erosion

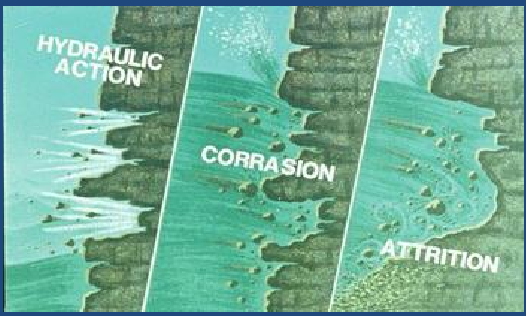
## Caves/Blowholes/Arches/Stacks

**1) Waves crash into headlands eroding weaker parts such as cracks.**

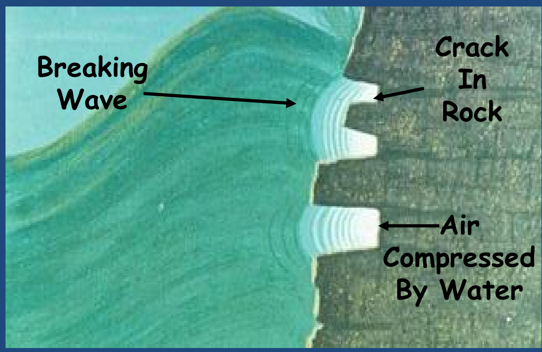
**2) The cracks are eroded by 3 different processes:-**

- **Hydraulic pressure**
- **Corrasion**
- **Attrition.**

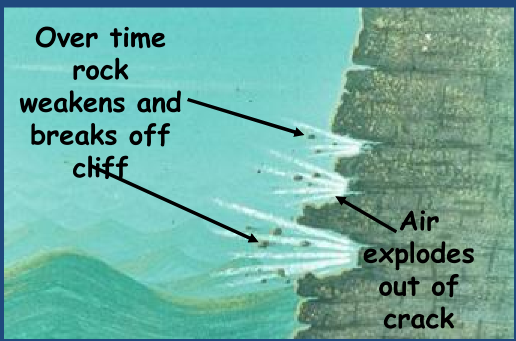
## Types Of Erosion



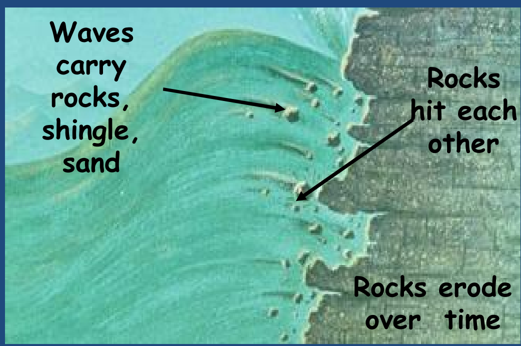

## Hydraulic Pressure



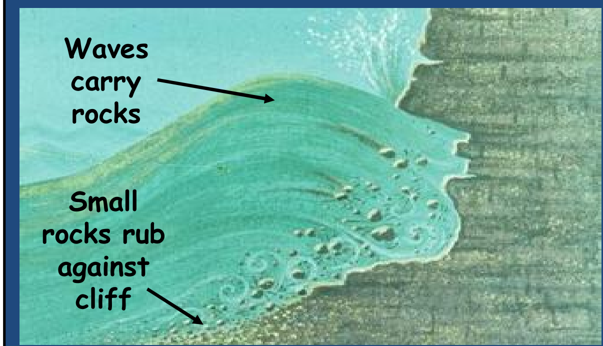

## Hydraulic Pressure



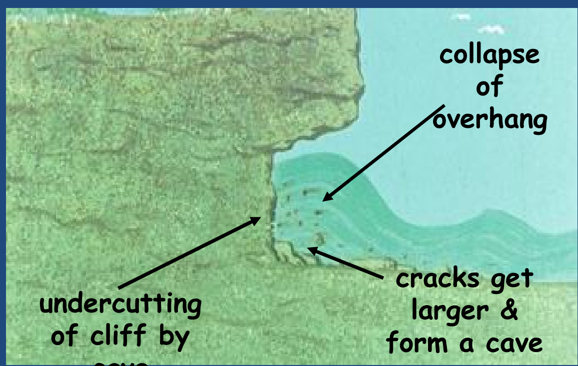

## Corrasion

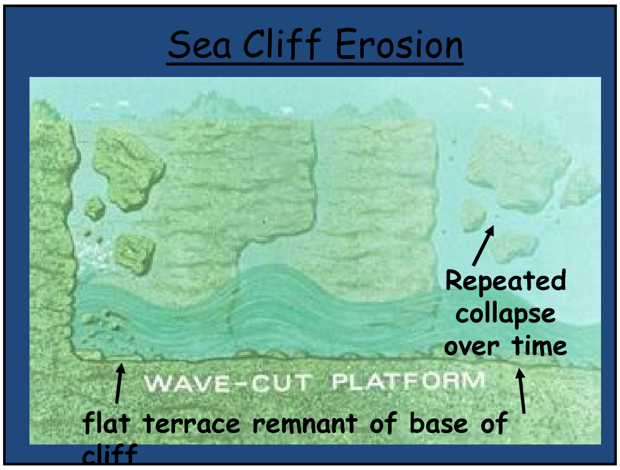


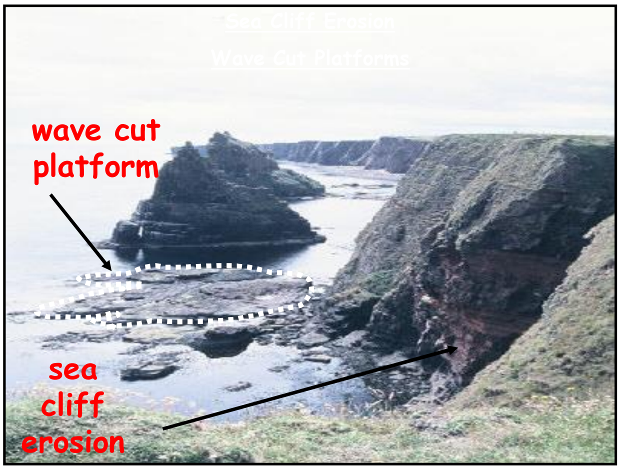

## Attrition

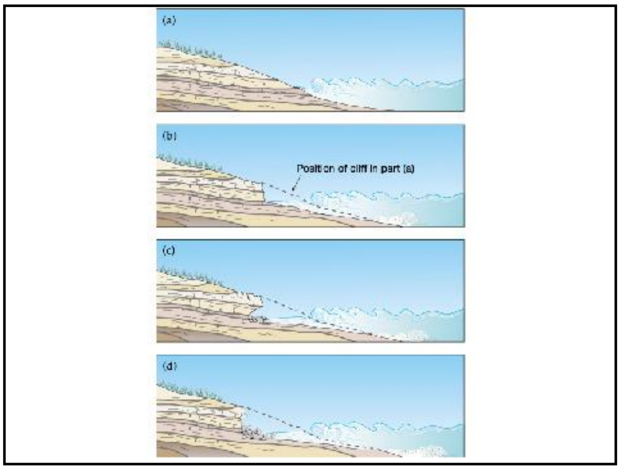


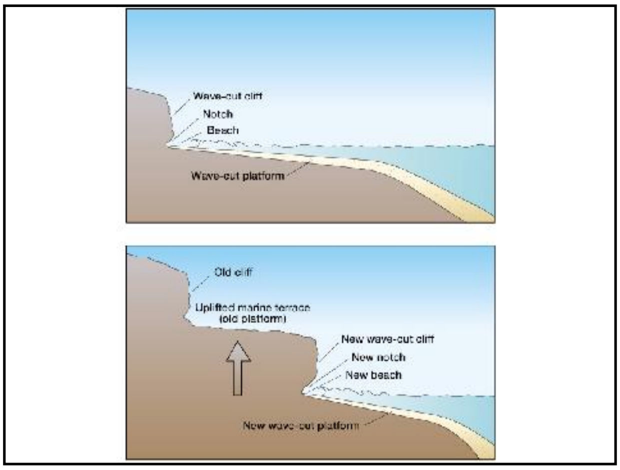

## Sea Cliff Erosion

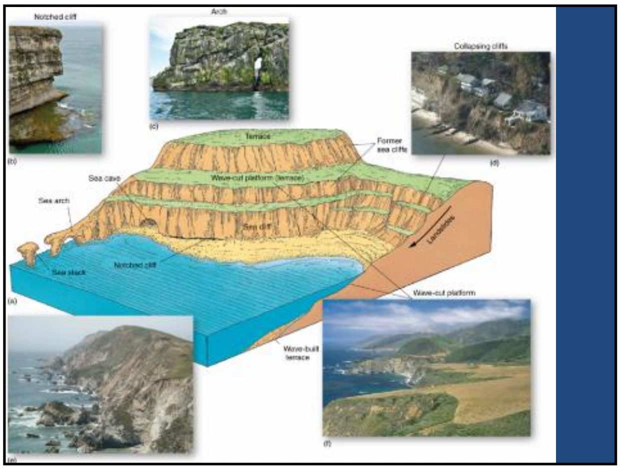


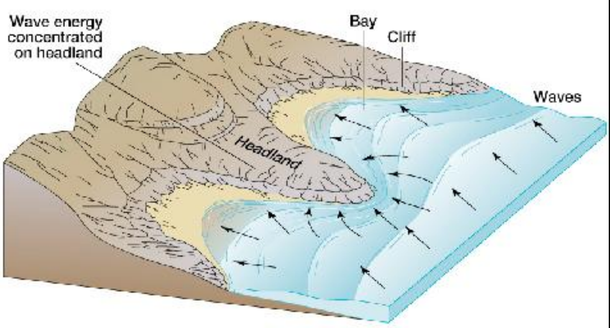

Sea Cliff Erosion
Repeated collapse over time
WAVE-CUT PLATFORM
flat terrace remnant of base of cliff


wave cut platform
sea cliff erosion

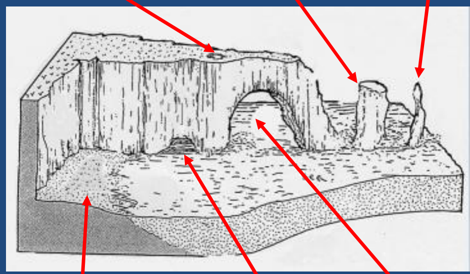

(a)
(b)
Position of cliff in part (a)
(c)
(d)


Wave-cut cliff
Notch
Beach
Wave-cut platform
Old cliff
Uplifted marine terrace (old platform)
New wave-cut cliff
New notch
New beach
New wave-cut platform

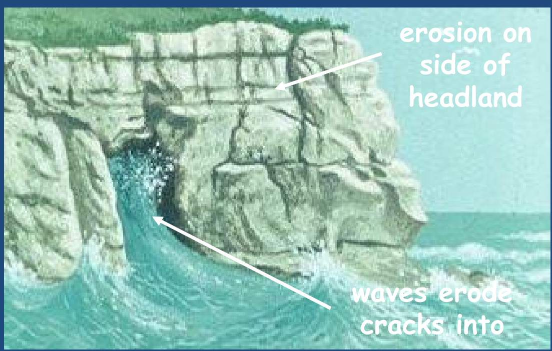

Notched cliff
Arch
Collapsing cliffs
Terrace
Former sea cliffs
Wave-cut platform (terrace)
Sea cave
Sea arch
Sea stack
Notched cliff
Wave-cut platform
Wave-built terrace




## Caves/Blowholes/Arches/Stacks




## Caves/Blowholes/Arches/Stacks 1




3) The crack starts to widen and form a cave, it can be undercut causing the roof to collapse due to lack of support for the roof. This helps the cave get larger.

4) As the cave gets larger, waves start to hit into its back wall and on impact are sent crashing into the roof of the cave where erosion occurs.

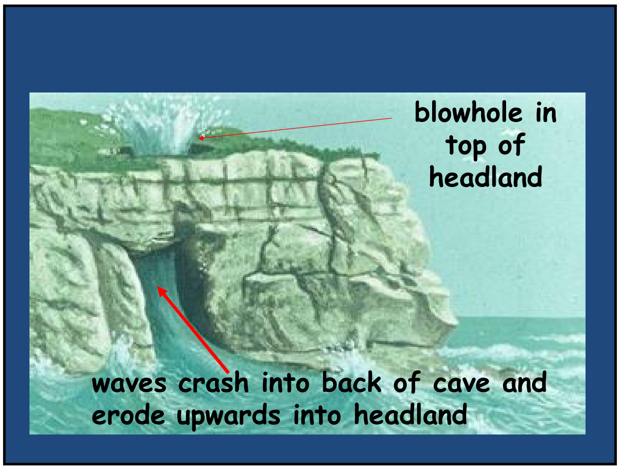
5)The erosion of the cave roof can lead to a blowhole, where waves continue to erode upwards and through the top of the headland. This is quite rare and needs a vertical crack line to be exploited (Sedimentary Rocks!).

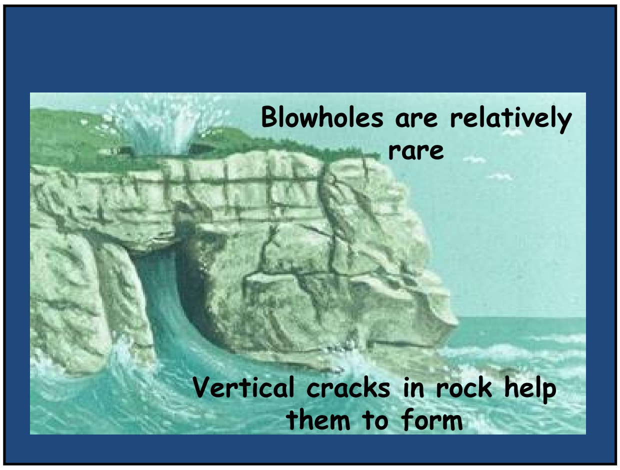
8) Over time the waves continue to widen the walls of the arch leaving less support for the roof, leading to its collapse. This leaves a new headland on the landward side of the arch and the old wall still standing on the seaward side.

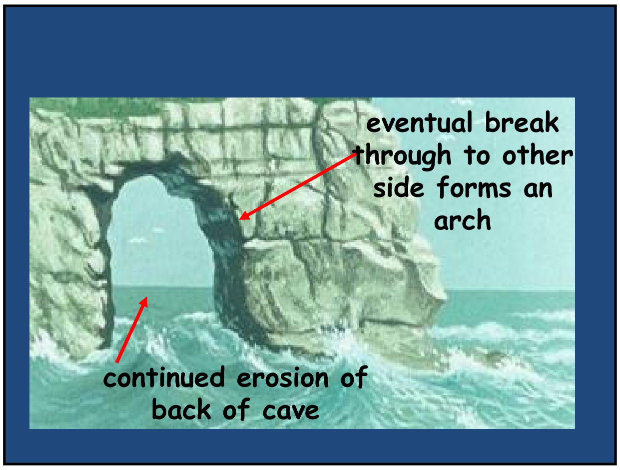
9) This old wall is called a stack or a pillar and is also subject to erosion by the sea. As it erodes it gets thinner at its base and parts of it collapse leaving a narrower pillar called a needle.

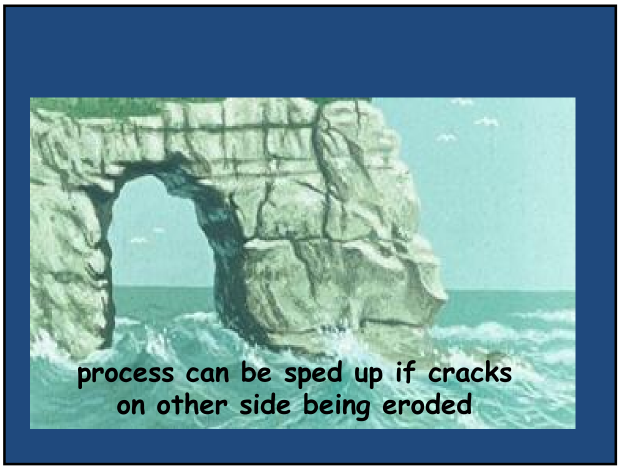
6) At the same time caves and blowholes develop, wave erosion can also lead to the development of an arch. This is when the cave erodes all the way through to the other side of the headland.

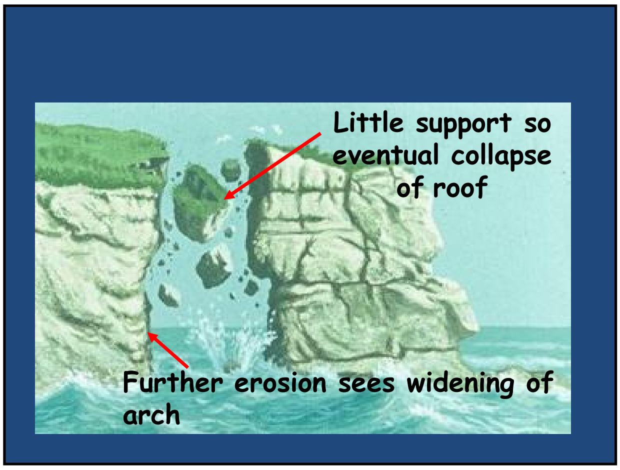
7) There may be similar cracks on the other side of the headland with erosion taking place, speeding up the development of the arch. Arches don't necessary need blow holes to be present when they develop!


blowhole in top of headland
waves crash into back of cave and erode upwards into headland

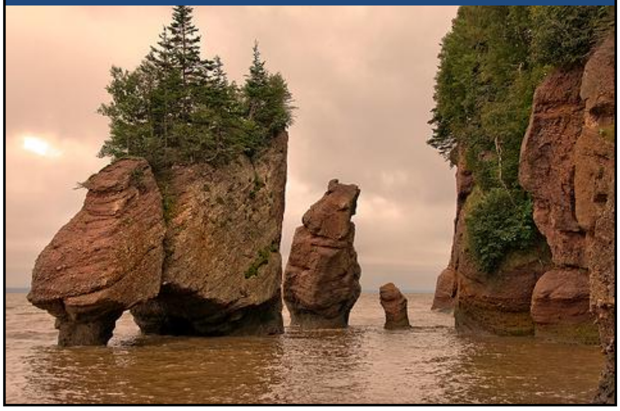

Blowholes are relatively rare
Vertical cracks in rock help them to form


eventual break through to other side forms an arch
continued erosion of back of cave


process can be sped up if cracks on other side being eroded


Little support so eventual collapse of roof
Further erosion sees widening of arch

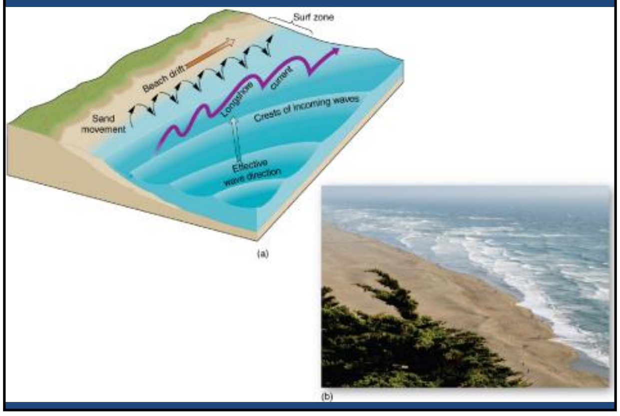

## *Flower pot rocks*



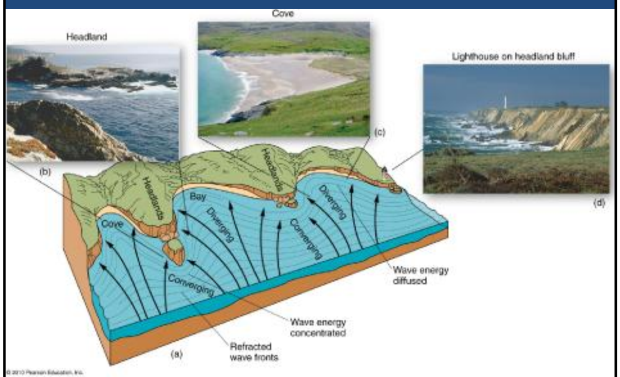


Sea Stacks

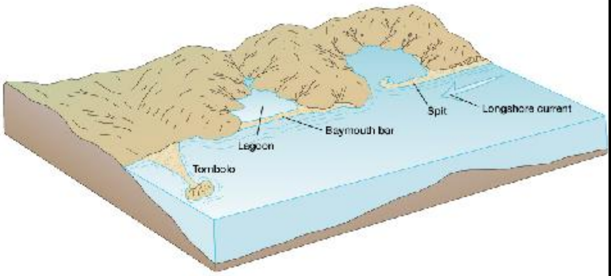
## Longshore Current and Beach Drift



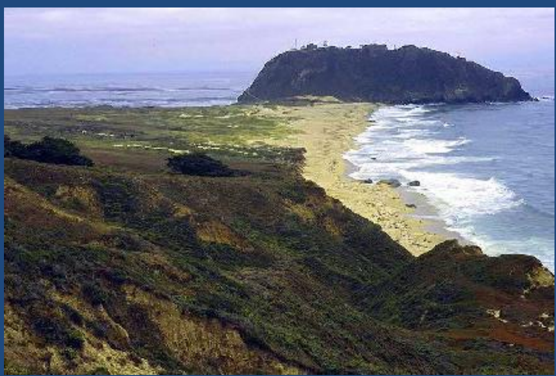

## Coastal Straightening



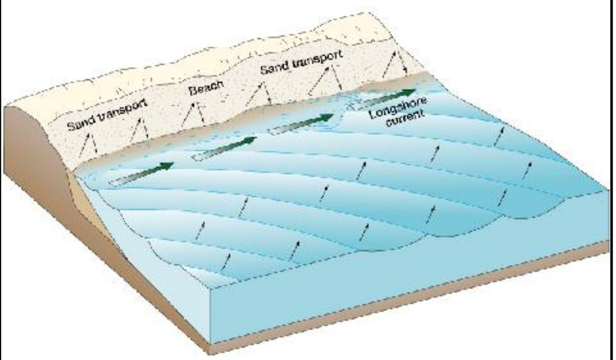
# Depositional Coastal Features

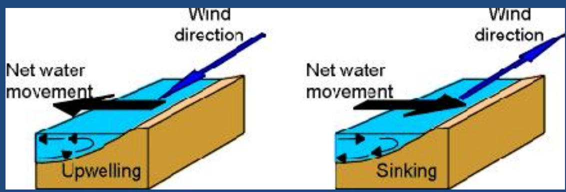

# Tombolo



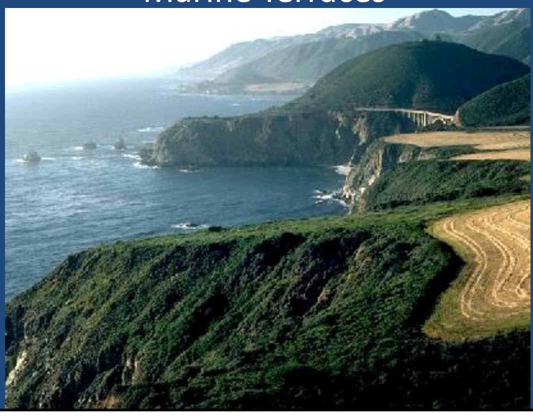
# Tombolo




## Depositional Coastal Features



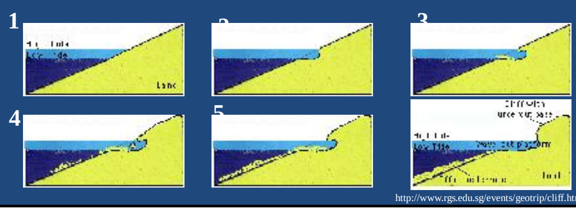

## Marine Terraces



**Wave-cut platform**

Horizontal benches in the tidal zone extending from the sea cliff out into the sea

If the sea level relative to the land changes over time (becoming lower with respect to the land due to uplift), multiple wave cut platforms (terraces) result




http://www.rgs.edu.sg/events/geotrip/cliff.html

## Emergent Coastlines

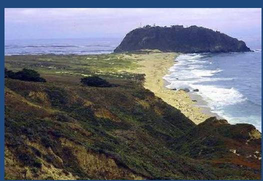
**Tectonic forces lift coastlines faster than sea-level rises. Dramatic cliffs and marine terraces tower above the sea.**

COASTAL FLUVIAL PROCESSES/LANDFORMS

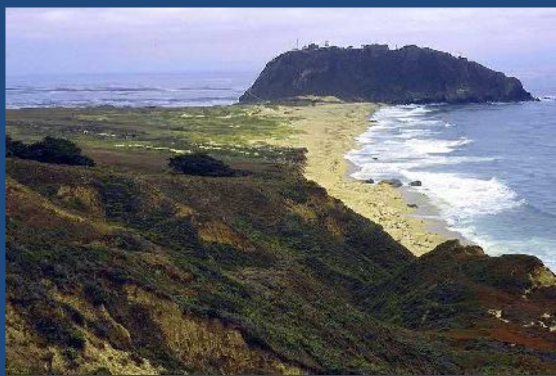
- Coastal Transportation - wave action creates strong currents parallel to shore. Large waves move beach sand offshore. Small waves push it back on shore.
- Longshore current

Coastal Deposition – where wave action is reduced, beaches and dunes form.

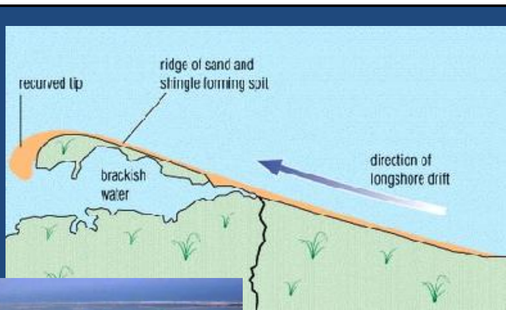
- beaches
- dunes
- sand spits



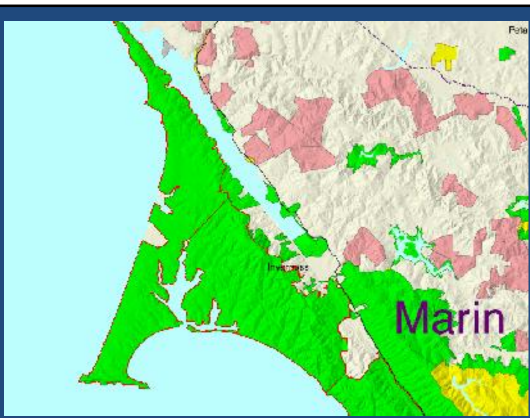
## Tombolo



## Tombolo




Sand Spit



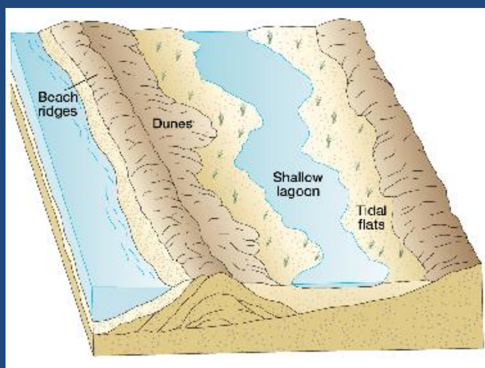

Sand Spit

Sand Spit


Sea Stacks

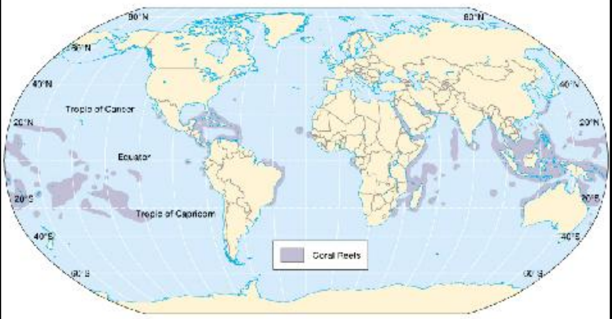

Natural Bridges and Arches

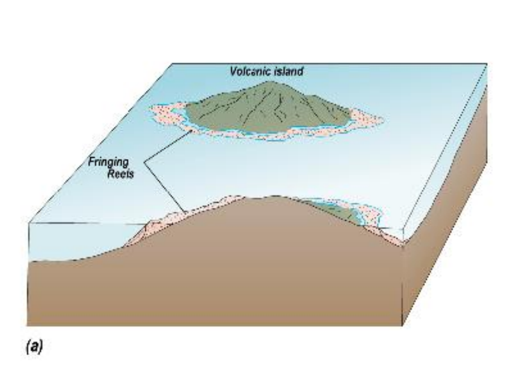
Barrier Islands

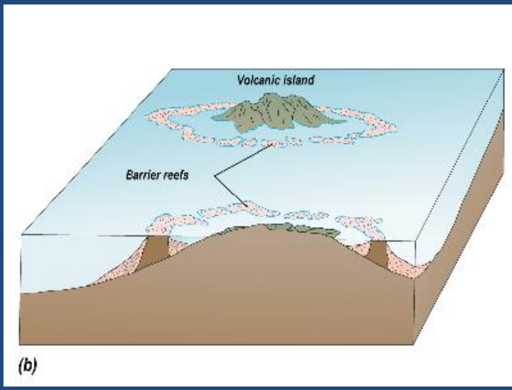


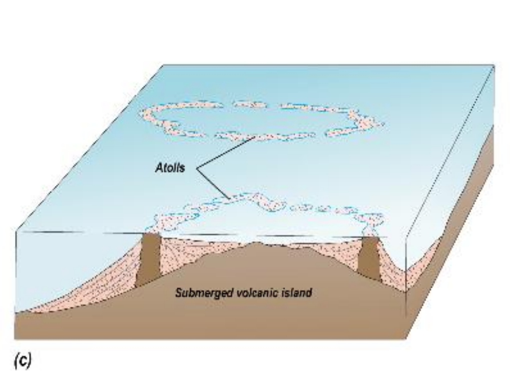

## Factors Correlated with Healthy Coral Reef Growth

- water temperature range: 18 – 29îC
- normal seawater salinity: 32 – 35 ‰
- clear, transparent water
- little or no sedimentation
- vigorous water motion




Tropical Mangroves

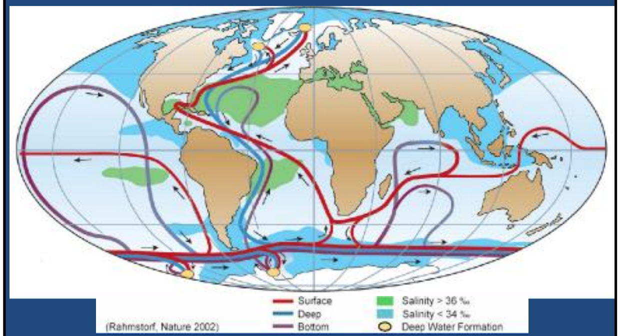
Thermohaline Circulation (THC)

The Global Conveyor Belt

# What is it?

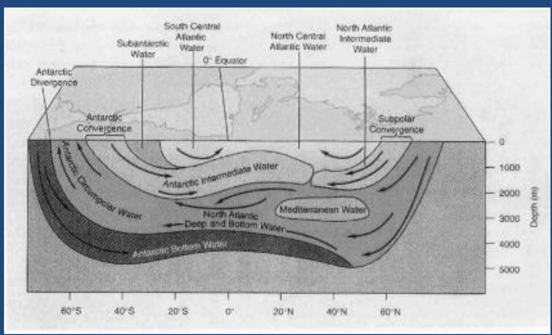
- "…that part of the ocean circulation which is driven by fluxes of heat and freshwater across the sea surface and subsequent interior mixing of heat and salt" (Rahmstorf, 2006)

- One driving mechanism of large-scale "deep" ocean circulation
- Temperature + salinity ⟶ density
  - "Thermo-" + "-haline"
- Requires turbulent mixing to complete the circulation
- Physical concept, not observational

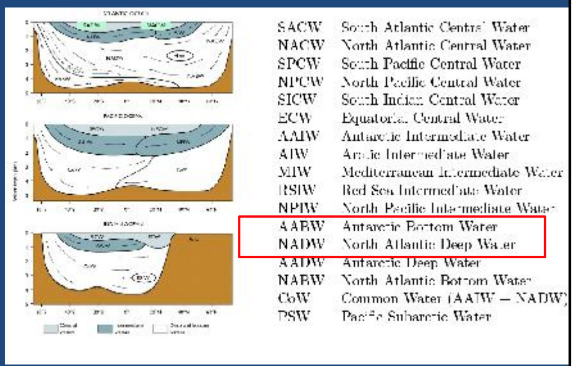


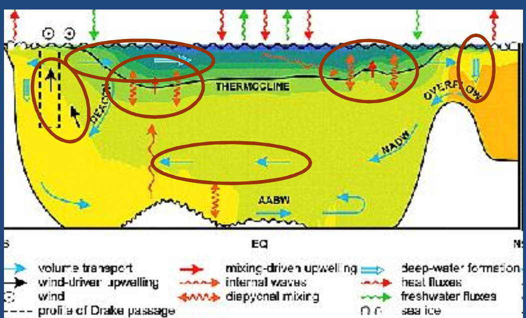

Source: Rahmstorf (2006)

## Idealized representation of abyssal circulation.




## Major Water Masses




Idealized meridional section representing a zonally averaged picture of the Atlantic Ocean. Straight arrows sketch the MOC. The color shading depicts a zonally averaged density profile derived from observational data [Levitus, 1982].

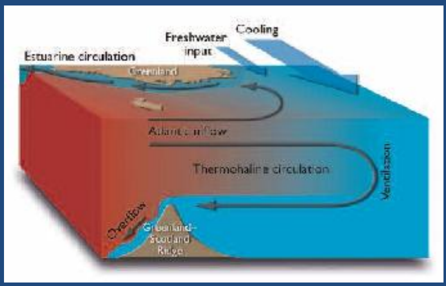
# Why is it important?

- Maintains ocean stratification
- Comparable transport to that of the surface
  - Global volume transport ~ 30 Sv
- Climate modulator
  - Cold water absorbs $CO_2$ more efficiently
  - THC modulates heat transport
    - ~ 1 PW ($10^{15}$ W) in N. Atlantic

## Speculation about the future…

- Global warming – warming and freshening
- Will the THC break down?
  - Low probability, high impact
  - Most likely scenario – weakening of THC
  - Would take decades to centuries to change
  - No "Day After Tomorrow" scenario…☹

## Formation of North Atlantic Deep Water (NADW)




Formed by surface cooling in Greenland and Norwegian Seas. Water sinks and accumulates north of Iceland. Pulse of NADW intermittently spill over sills, cascading into the Atlantic basin. During this processes it entrains significant amounts of overlying water. Resulting water is ~ 2-4°C and 34.9 to 35 psu.

## Thermohaline circulation

S

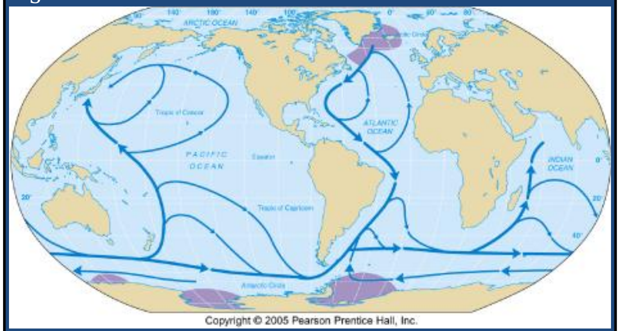
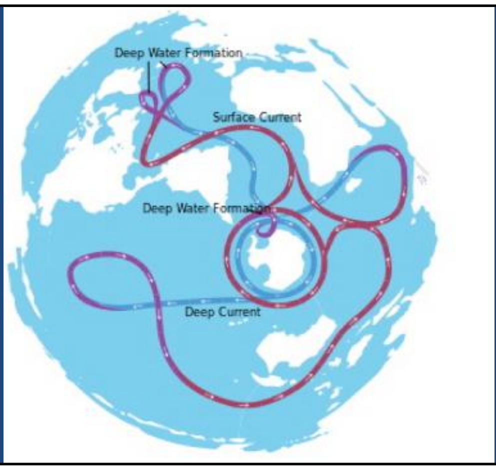



Fig. 7.26

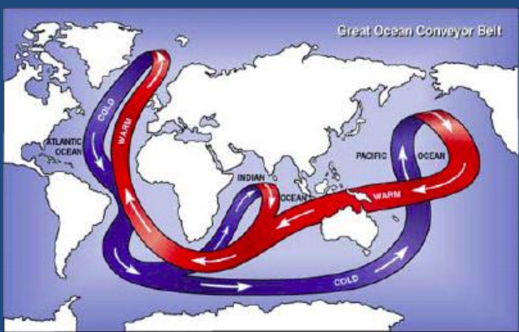
## P Conveyor-belt circulation

- Combination deep ocean currents and surface currents


"What goes around, comes around" - the time to complete a cycle (or the residence time in the deep ocean) is from 750-1,000 years.

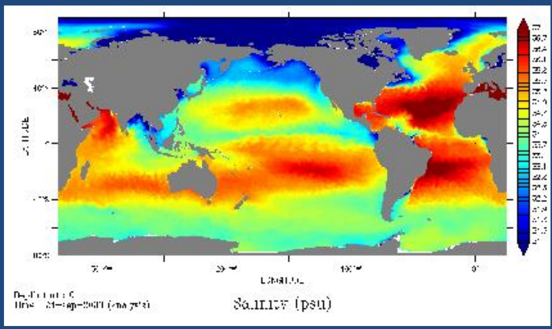



## Role of Thermohaline Circulation in Climate

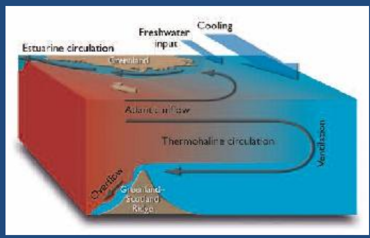



Upper limb of conveyor is warm ~ 10°C, while NADW is cold ~ 3°C. Each $cm^3$ of upper-limb water releases 7 calories of heat when converted to NADW. Given the estimated flux of 20 Sv, this totals $4 \times 10^{21}$ calories each year. This is 35% of the heat received from the Sun by the Atlantic north 40° latitude. It is estimated that without the conveyor circulation, surface water in North Atlantic would be 5 degrees colder.

No deep water is formed in the North Pacific because the water is too fresh. Even when cooled to the point of freezing, it does not reach a density to sink all the way to the bottom.




Strong thermohaline circulation mixes with the relatively fresh Arctic water, keeping the salinity relatively high. This allows for the formation of NADW.




However, formation of NADW is very sensitive to salinity. If waters in the Artic get fresher it is possible, that this could weaken or shut down the conveyor circulation.

It has been suggested that there may be a feedback between the conveyor circulation and climate. Strong conveyor circulation leads to warmer arctic which melts back the polar ice. This dilutes the water in the North Atlantic preventing formation of NADW and shutting down the conveyor circulation. Without redistribution of heat by the conveyor, polar regions get colder, ice grows, water becomes more salty, which allows NADW to begin forming again. And so on and so on.

# Littoral Drift