OCEANOGRAPHY

10. Beaches, Shoreline Processes, and the Coastal Ocean

notes from the textbook, integrated with original contributions

Part 5

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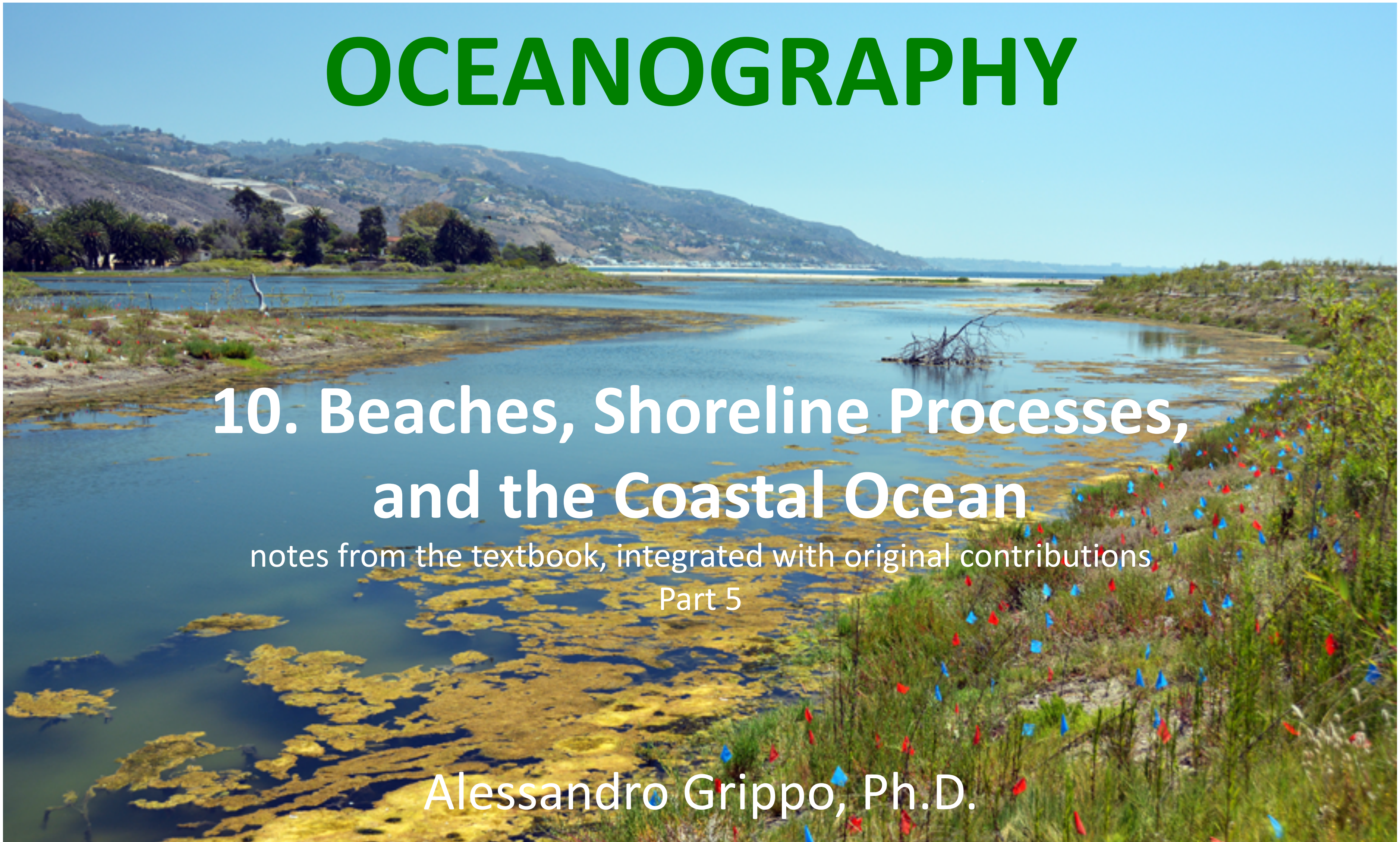


Malibu Creek enters the Pacific Ocean, while the ocean waves build up a sand bar, creating the conditions for the formation of a lagoon

Malibu Lagoon, Malibu, Los Angeles county, California

What Characteristics Do Coastal Waters Exhibit?

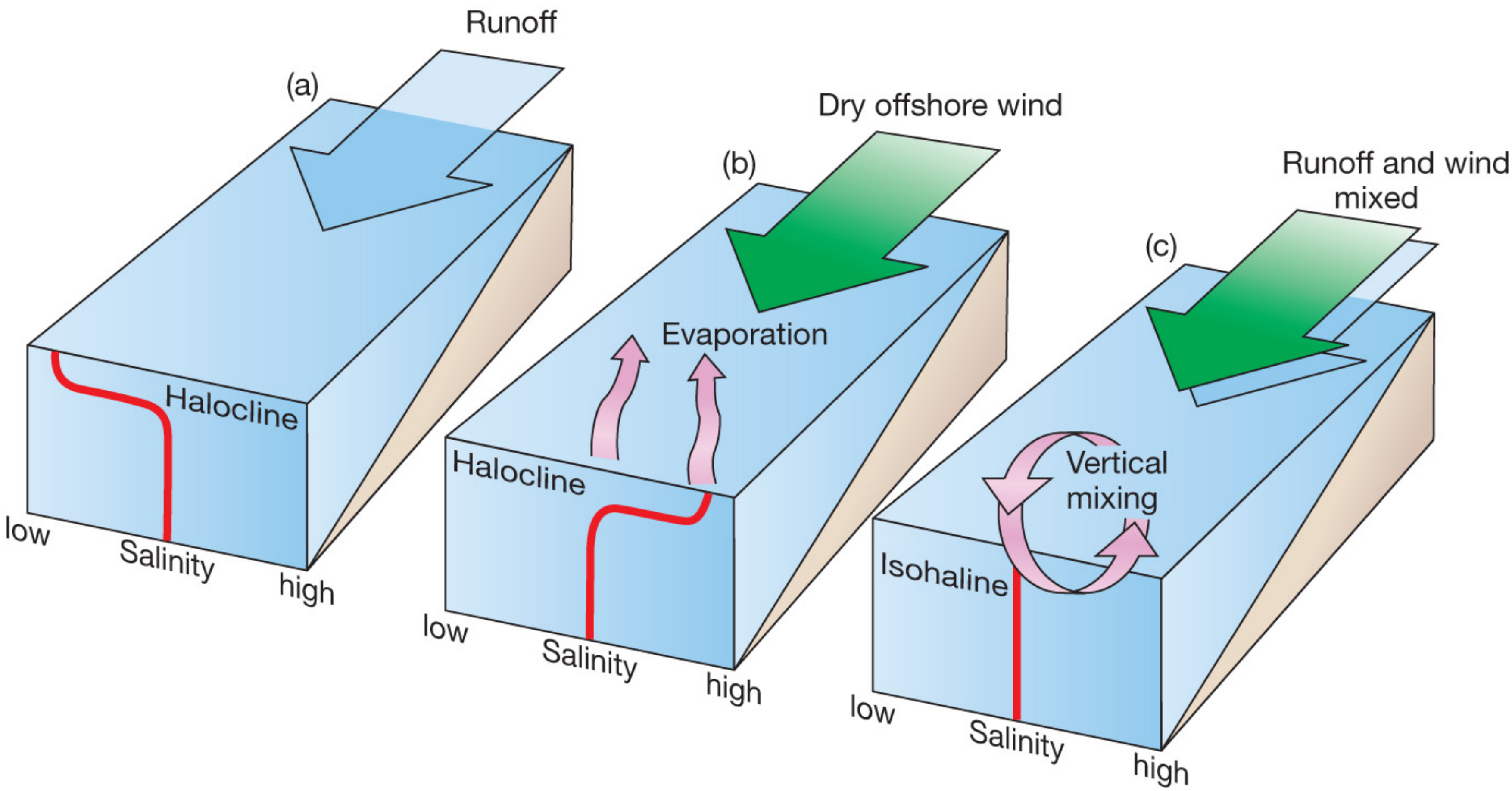
- Shallow-water areas adjacent to land (to edge of continental shelf)
  - can be wide (passive continental margins) or narrow (active continental margins)
  - beyond coastal waters lies the open ocean

- Because of their proximity to land, coastal waters are influenced by processes that occur on land
  - river runoff, wind, tides

Salinity in coastal waters

- Freshwater is less dense than seawater so river runoff does not mix well with seawater
  - Freshwaters from river runoff create a wedge at the surface, favoring the development of a halocline
  - Winds from land are usually dry and absorb moisture from the ocean, leaving behind a saltier body of water (with a *reversed* halocline)
  - Strong tides in shallow bodies of water can favor water mixing, and water can become isohaline

The way river runoff, winds, and tides action affect salinity in coastal waters

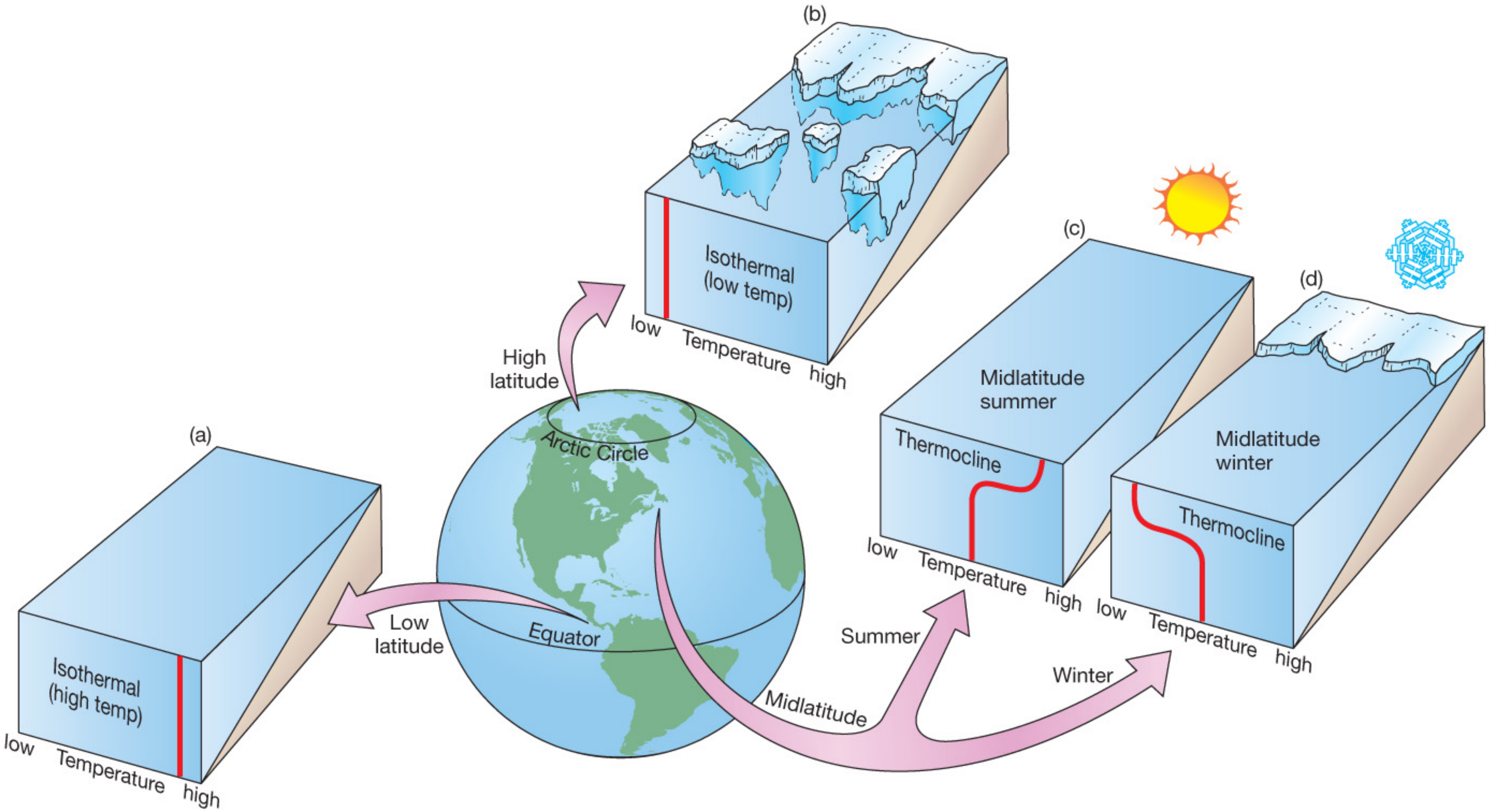


Temperature in coastal waters

- Water temperatures in coastal waters are variable, according to latitude, restrictions to water circulation, winds

- At low latitudes waters can be uniformly warm up to 45°C
- At high latitudes, sea ice can form at the surface, and water can be uniformly cold
- At mid latitudes, we have the development of a thermocline in function of the different seasons
  - regular during summer
  - reversed during winter
  - Mixing caused by wind can cause a progressive deepening of the thermocline

The way latitude affects temperature in coastal waters

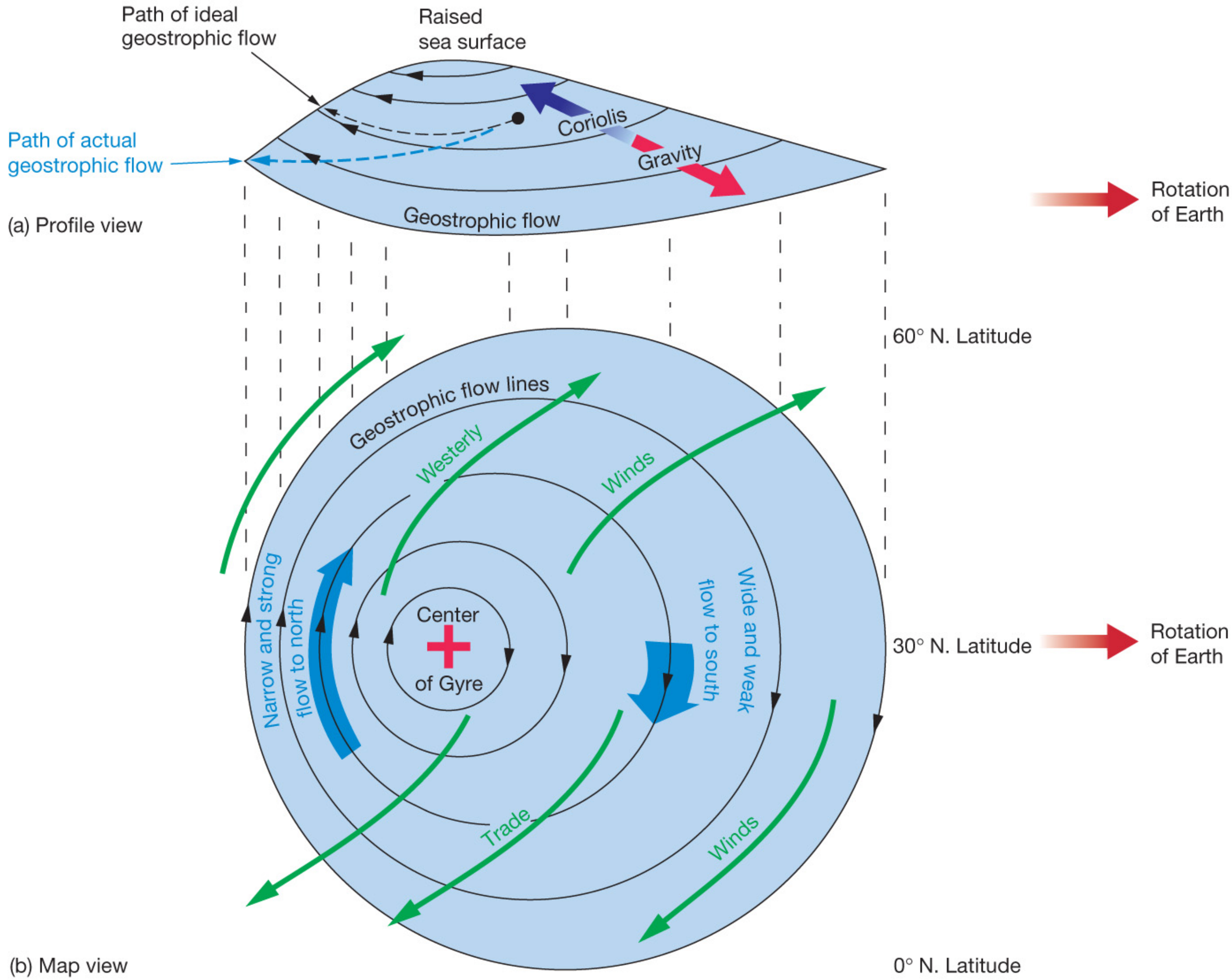


Coastal **Geostrophic Currents**

- We have seen in Chapter 7 that geostrophic currents move in a circular path around the middle of a current gyre

- Wind and river runoff can create geostrophic currents in coastal waters too (coastal geostrophic currents)

Northern Hemisphere Subtropical Gyre



- Winds can blow water towards land and pile it up against the coast
  - When water moves back towards the open ocean, it will be deflected to the right in the northern hemisphere, to the left in the southern hemisphere

- Rivers can release a salt wedge into the ocean
  - Water can be deflected to the right in the northern hemisphere, to the left in the southern hemisphere

- Coastal geostrophic currents are variable because they depend on the wind and the amount of runoff
  - If winds are weak, or river runoff volume is low, these currents are also very weak

- Coastal geostrophic currents are bounded by the coastline on one side and by steadier, stringer eastern or western boundary currents on the ocean side

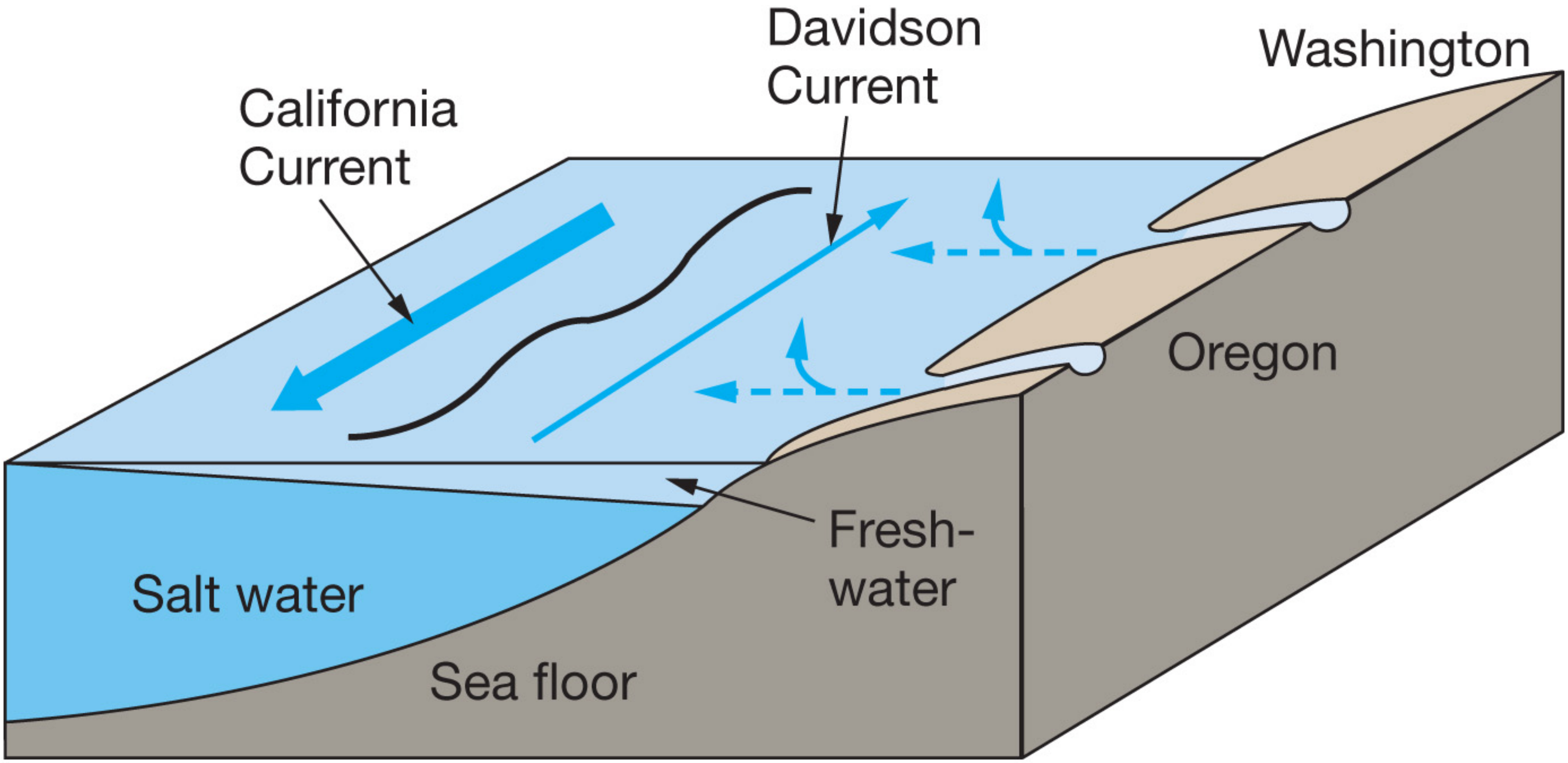
A coastal geostrophic current: the Davidson Current offshore Washington & Oregon

- Heavy rains during winter increase river runoff along the NW Pacific coast
  - Water is deflected to the right (northward)

- Strong southwesterly wind enhance this motion

- The Davidson Current develops between the coastline and the eastern boundary California Current

The Davidson Current



What types of Coastal Waters exist?

- The most important types of coastal waters include:
  - Estuaries
  - Lagoons
  - Marginal Seas

Estuaries

- An estuary is a partially enclosed coastal body of water where freshwater runoff from a river (or melting ice) dilutes the input of salty ocean water

- Estuaries are marine environments where salinity, temperature, pH, water levels vary depending on the local interaction between freshwater from land and saltwater from the ocean

- The mouth of a river, a bay, an inlet, gulfs, sounds, are all examples of estuaries
- The mouth of large rivers can often constitute an economical resource
  - Seaport
  - Fisheries
  - Ocean commerce


Buenos Aires
Montevideo
Rio de La Plata
Rio De La Plata (River of Silver), between Argentina and Uruguay


Utrecht
The Hague
Ede
Arnhem
Rotterdam
's-Hertogenbosch
Breda
Tilburg
Eindhoven
Rhine River, Netherlands

Origin of estuaries

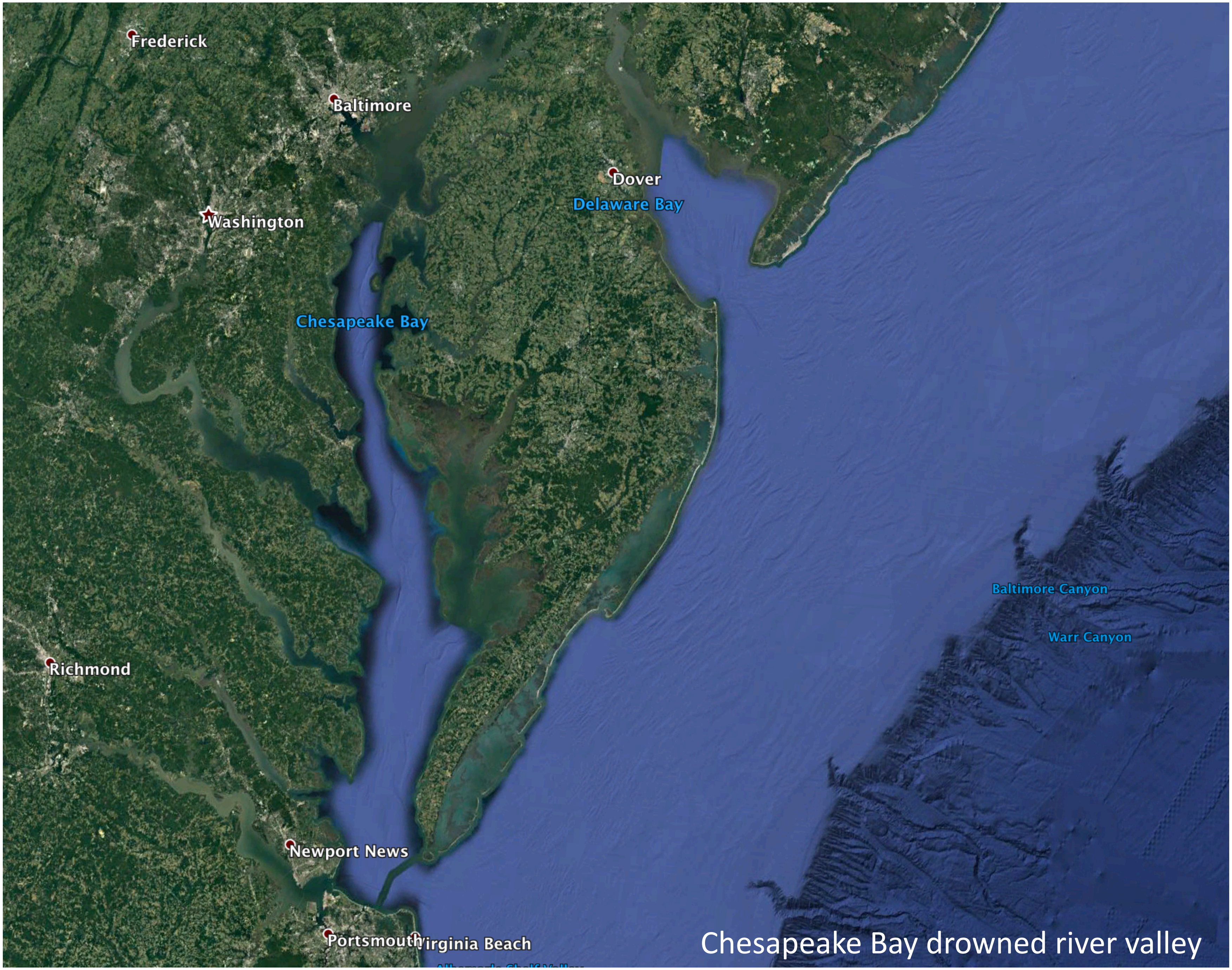
- Estuaries of today exist mainly because sea level has been rising up to 120 m since the peak of the last glaciation

There are four main types of Estuaries

- Coastal plain estuaries
- Fjords
- Bar-built estuaries
- Tectonic estuaries

1. Coastal Plain Estuaries

- Coastal plain estuaries
  - Form when river valley (carved on land) are flooded with seawater as sea level rises
  - These are also called drowned river valleys
  - Valleys carved by rivers have a typical V-shape profile
  - Examples:
    - Chesapeake Valley in Maryland, District of Columbia, and Virginia


Frederick
Baltimore
Dover
Delaware Bay
Washington
Chesapeake Bay
Baltimore Canyon
Warr Canyon
Richmond
Newport News
Portsmouth
Virginia Beach
Chesapeake Bay drowned river valley

2. Fjords

- Fjords
  - Form when glaciated valley is flooded with seawater as the sea level rises
  - The term is Norwegian, where fjords dot the whole coastline
  - Glacial valleys have a characteristic U-shape with steep walls, distinct form the gentler V-shape of river valleys
  - A glacial moraine is commonly found at the ocean entrance. Moraines are glacial deposits that mark the advance of glaciers
  - Examples:
    - Norway, Alaska, western Canada, southern Chile, New Zealand


Sognefjord
Bergen
Norway
Hardangervidda
Haugesund
Fjords along the coast of Norway

3. Bar-Built Estuaries

- Bar-built estuaries
  - Consist of shallow bodies of water separated from the open ocean by sand deposits called sand bars
  - Sand bars are deposited parallel to the coastline because of wave action
  - The area behind the sand bar is a lagoon
  - A lagoon that separates the mainland from a barrier island is an example of a bar-built estuary

  - Examples
    - Several parts of the world, but common in the United states along the Gulf of Mexico coast and the East Coast south of Massachusetts

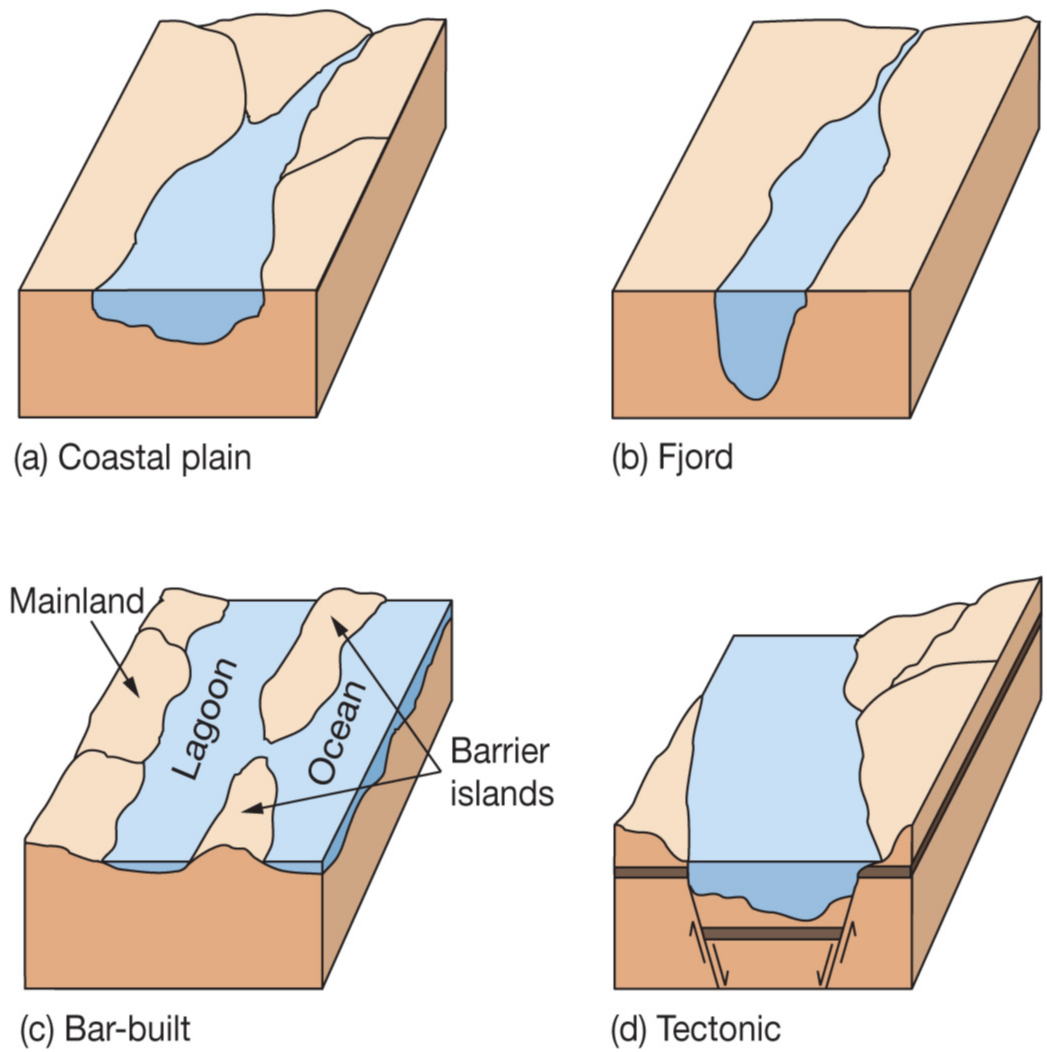
Padre Island (barrier island) and Laguna Madre (lagoon) by Corpus Christi, along the coast of Texas

4. Tectonic Estuaries

- Tectonic estuaries
  - Form when faulting or folding of rocks create a restricted downdropped area into which the ocean can enter
  - Examples:
    - San Francisco Bay, California

San Francisco Bay, California, is bounded to the west by the San Andreas Fault, and to the east by the Hayward Fault. The central block between these two faults collapsed, and the area was flooded by the Pacific Ocean

Types of Estuaries



Water Mixing in Estuaries

- Because freshwater from rivers is less dense than sea water, the basic flow pattern in an estuary is:
  - Surface flow of less dense freshwater moving out towards the ocean
  - Bottom flow of more dense saltwater moving in from the ocean into the estuary
  - This kind of circulation is called estuarine circulation

- Based on the physical characteristics of the estuary and the resulting mixing of freshwater and seawater, we identify four types of estuaries

Water Mixing in Estuaries

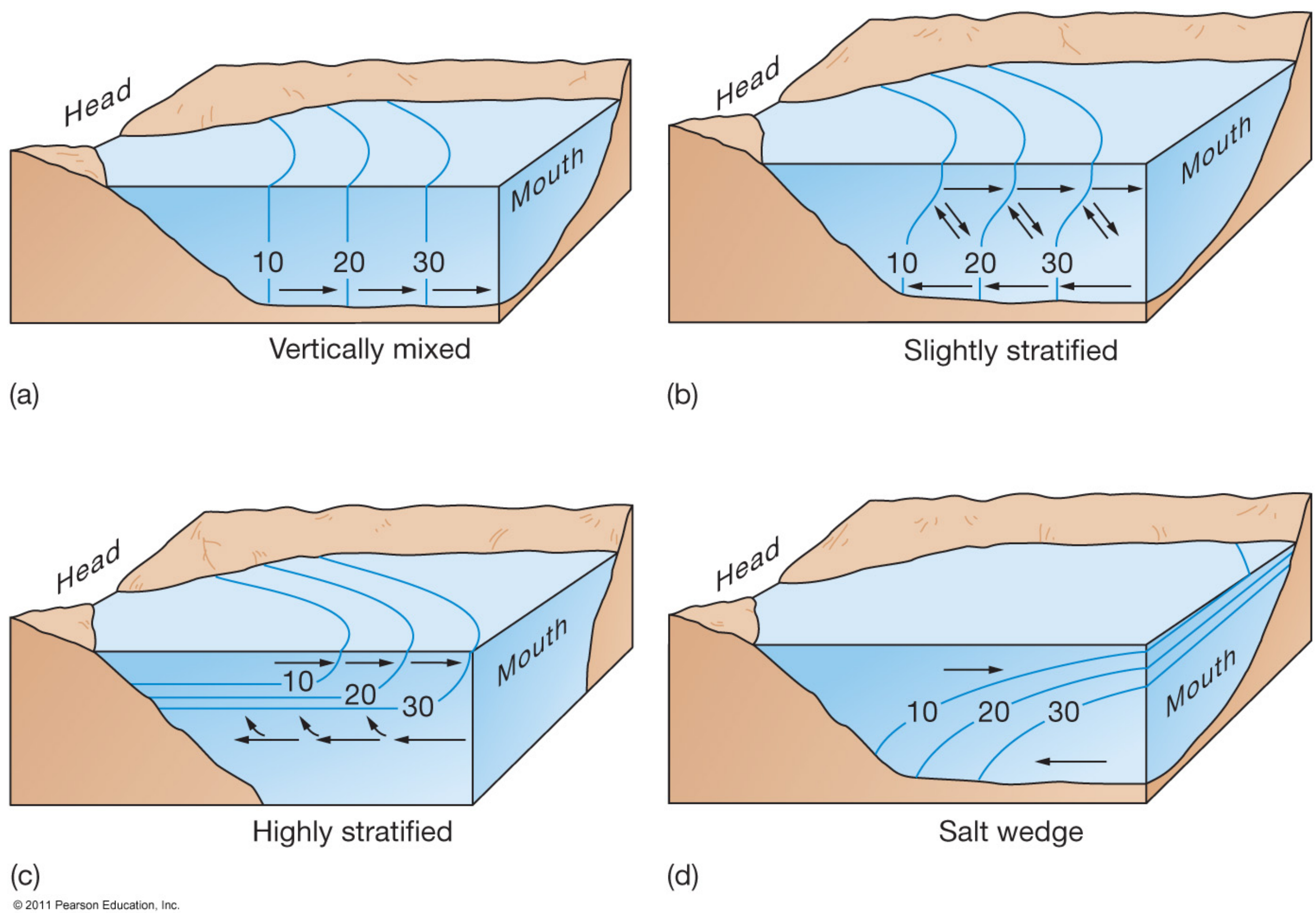
- Vertically mixed estuary
  - Shallow, low volume estuary
  - Salinity is uniform with depth
- Slightly stratified estuary
  - Deeper than the previous
  - Salinity increases from head to mouth at any level
    - two layers can be identified
      - Upper layer less salty; lower layer more salty
  - Estuarine circulation starts to develop

Water Mixing in Estuaries

- Highly stratified estuary
  - Deep, relatively strong halocline
  - Surface layer salinity decreases to ocean value on the way out
  - Lower layer salinity is constant and typical of open ocean

- Salt wedge estuary
  - Typical of mouth of deep, high volume rivers
  - A wedge of salt water intrudes from the ocean beneath the river water
  - Strong halocline

Estuary Classification by Mixing



Estuaries and Human Activities

- Estuaries are:
  - Important breeding grounds and protective nurseries for many marine animals
- But also:
  - Estuaries support shipping, logging, manufacturing, waste disposal and other activities that can potentially damage the environment
- Pressures from increasing human populations
  - Estuaries can be damaged where human population is large, but also where populations are still modest
    - Example:
      - Columbia River Estuary
      - Chesapeake Bay

Columbia River Estuary

- Salt wedge estuary
  - Strong flow of river and tides drive salt wedge as far as 42 km /26 mi upstream, raising river level by 3.5 meters (12 feet)
  - When tides ebb, the huge flow of freshwater creates a freshwater wedge that extends hundred of km into the Pacific Ocean

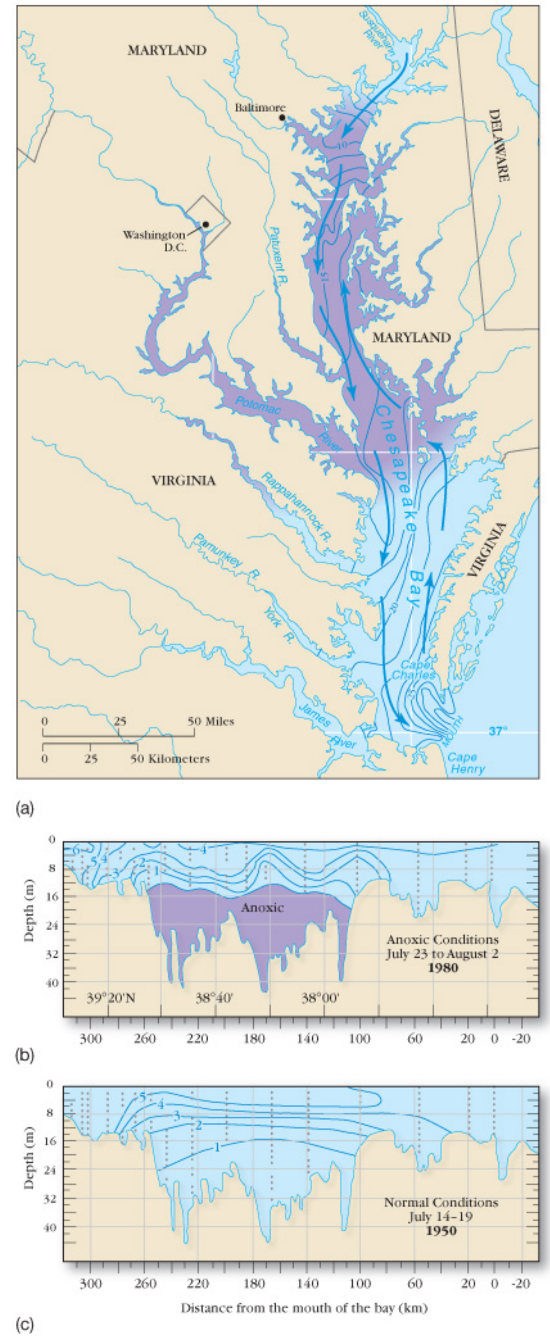
Columbia River Estuary

- Damage done by building dikes to protect from flooding of agricultural areas
  - Lack of new nutrient for soil
- Dams altered ecosystem
  - Necessary for flood control, electrical power, and as a dependable source of water
  - Damaged ecosystems (salmons for instance)
  - Dams stop sediment: it becomes necessary to dredge sediment to keep navigation possible
  - Dredging brings pollution
- Logging industry damage
  - More sediment added to the river

Chesapeake Bay Estuary

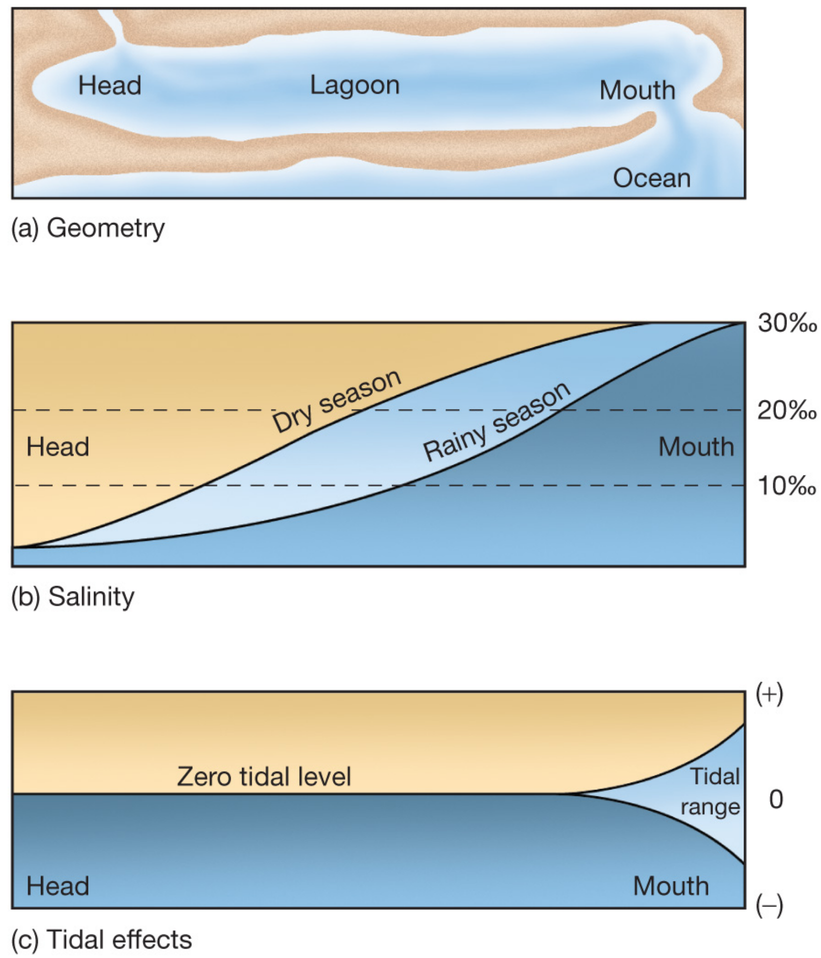
- Chesapeake Bay is a drowned valley along the east coast of the U.S.
- 320 km / 200 mi long, 56 km / 35 mi wide
- Largest and best studied estuary in the U.S.
- 17700 km / 11000 miles of coastline length
- 16 million people live around this estuary

- Slightly stratified estuary
- Experiences large seasonal changes in salinity, temperature, dissolved oxygen
- Isohalines are parallel to coastline because of the Coriolis effect
- Anoxic conditions develop below the pycnocline in summer because the great flow of freshwater prevents mixing with salty ocean waters
- Use of fertilizers increases algae productivity
  - Will create even more organic matter at the bottom where water does not circulate
  - Lower runoff mitigates anoxic conditions
- Major kills of commercially important marine animals



Lagoons

- Protected, shallow water bodies landward of barrier islands
- Typical of bar-built estuaries
- Because of restricted water circulation between lagoons and the ocean, three distinct zones can usually be identified within lagoons:
  - Freshwater zone
    - Near the head of the lagoon, where rivers enter
  - Transition zone of brackish water
    - Near the middle of the lagoon
  - Saltwater zone
    - Close to the lagoon mouth



Laguna Madre, Texas

- Located along the coast of south Texas, from Corpus Christi to mouth of Rio Grande
- Protected from open ocean by Padre Island, a barrier island 160 km / 100 mi long
- The tidal range is very small (0.5 m), the inlets very tiny
  - As a consequence, there is very little tidal interchange between the lagoon and the open sea


2400
2200
2000
1200
1000
600
400
200
Austin
Beaumont
Houston
Sabine Lake
Del Rio
San Antonio
Galveston Bay
Victoria
Matagorda Bay
San Antonio Bay
Aransas-Copano Bays
Corpus Christi
Corpus Christi Bay
Laredo
Upper Laguna Madre-
Baffin Bay
Lower Laguna Madre
Brownsville

Laguna Madre, Texas

- Laguna Madre is a hypersaline lagoon
- It is less than 1 meter / 3.3 feet deep
- Great seasonal changes between summer and winter in both temperature and salinity
  - Salinities range from 2 ppt to 100 ppt (ocean is 34.7 ppt)
  - Temperatures range 5°C to 32°C / 41°F to 90°F
  - High evaporation usually keeps salinity around 50 ppt
  - High salinity does not even allow salt-tolerant marsh grasses to live on the island, so a sand beach exists on both sides of Padre Island
  - At the inlet, salt ocean waters is less dense than lagoon water, so it flows in above the lagoon water itself
  - That pattern is the opposite of estuarine circulation

Marginal Seas

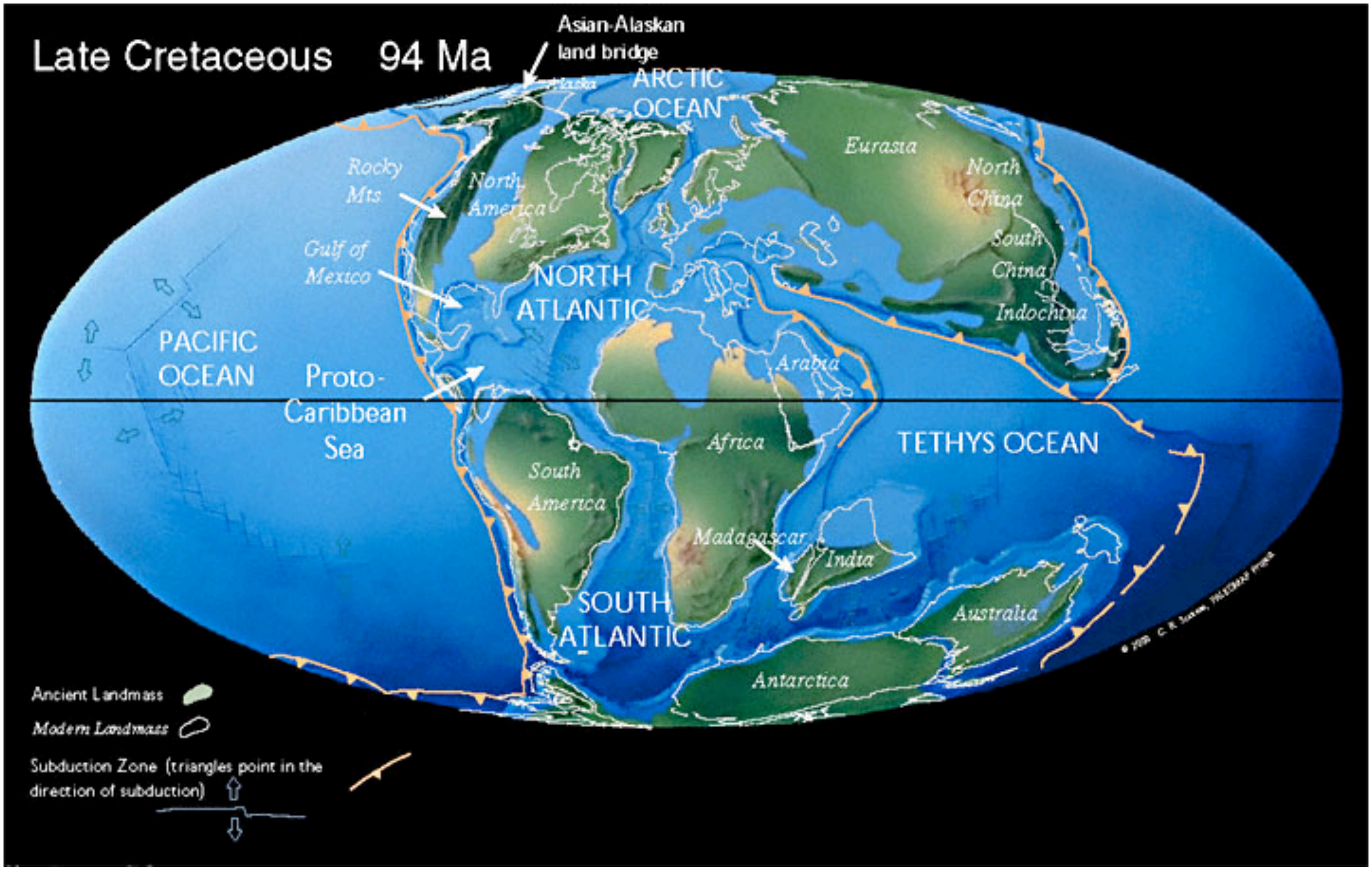
- Bodies of water at margin the ocean
- Semi-isolated from open ocean
- Most formed from tectonic events
- These waters tend to be shallower than open ocean
- Different ways to exchange waters with open oceans
- As a consequence, salinities and temperatures are different form open ocean

- Examples
  - Mediterranean Sea (isolated oceanic crust stuck between colliding continents, Europe and Africa; residue of ancient Tethys Ocean)
  - Caribbean Sea (created behind a volcanic island arc)

Mediterranean Sea

(a)

The Mediterranean Sea
as a remnant of the ancient Tethys Ocean



From: http://www.scotese.com/cretaceo.htm

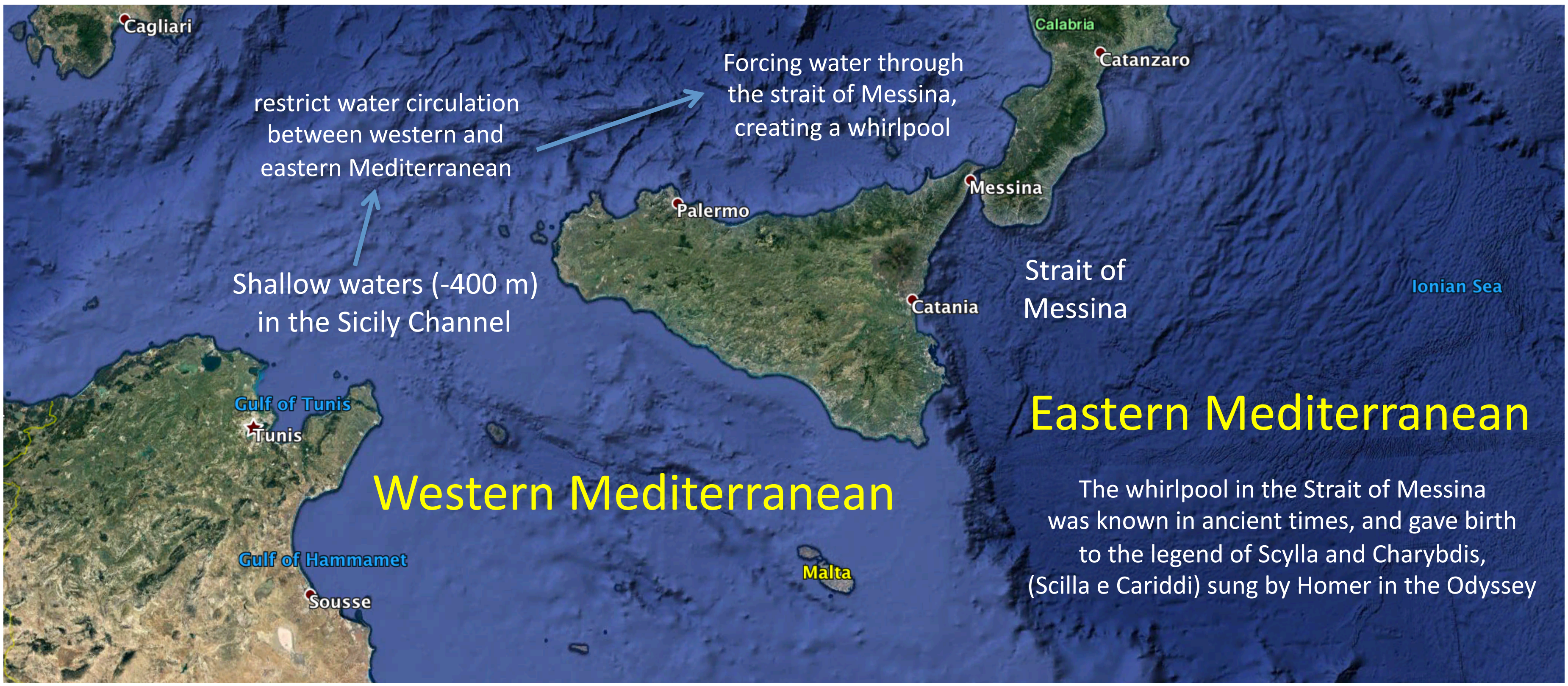
Mediterranean Sea

- Deeper than average marginal sea
- Has oceanic crust at the bottom (subduction south of Greece)
- Thick salt and gypsum deposits at the bottom suggest that the Mediterranean nearly dried up about 6 million years ago, only to refill again with a large saltwater waterfall

Mediterranean Sea

- Surrounded by continents (Europe, parts of Asia on the north, Africa on the south)
- Only a very narrow passage at Gibraltar allows exchange with open ocean waters of the Atlantic
- Black Sea and Suez canal also allow minor exchanges
- Irregular coastlines divides the Mediterranean into sub-seas, each with its own separate circulation pattern (Adriatic Sea, Aegean Sea, Ionian Sea, etc.)
- A shallow ridge (sill) between Sicily and Tunisia separates the Mediterranean in two basins, forcing water circulation through the straight of Messina, Italy

The sill in the Sicily Channel



Scylla and Charybdis were represented in Greek mythology as two immortal and irresistible monsters who beset the narrow waters crossed by the hero Odysseus in his wanderings described in Homer's *Odyssey*, Book XII. They were later localized in the Strait of Messina.

Mediterranean Sea Circulation

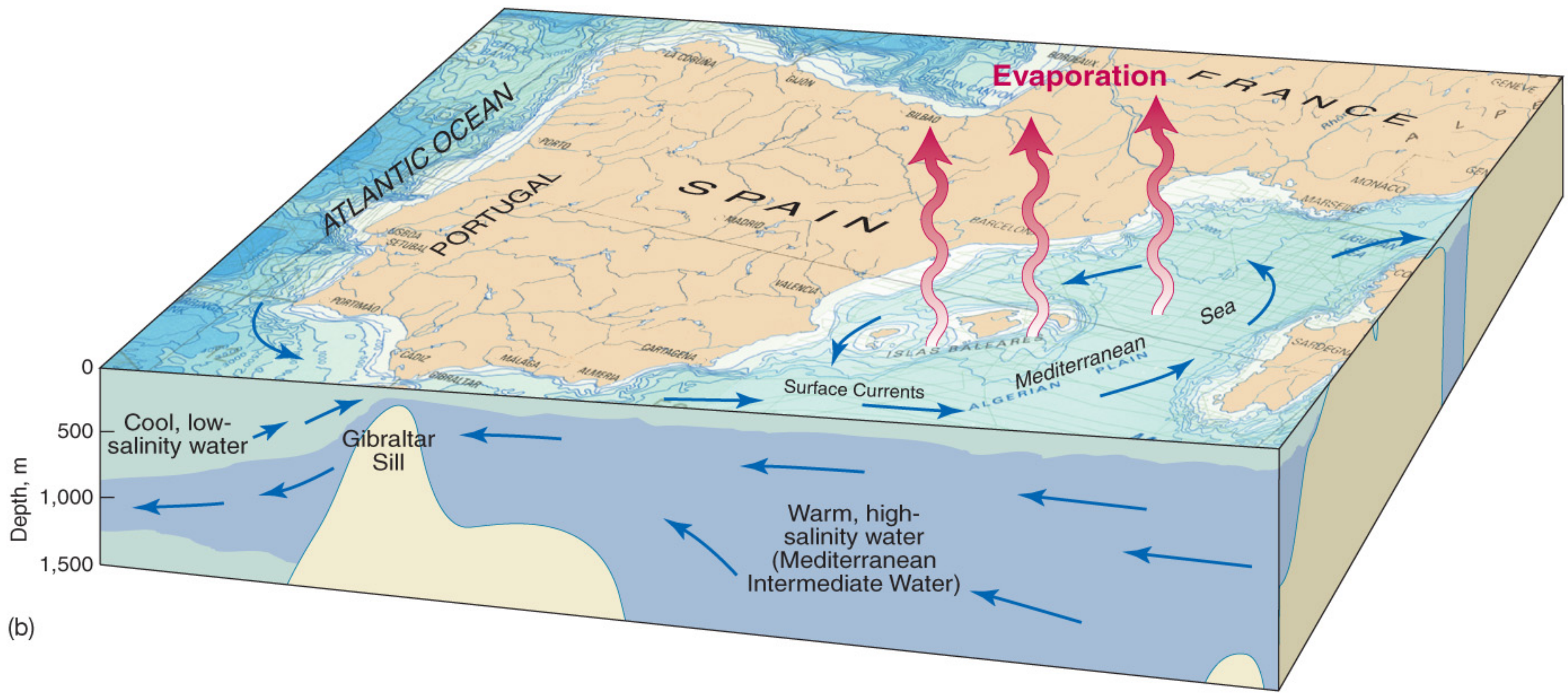
- Very unusual and unique circulation pattern
- High rates of evaporation in eastern Mediterranean are responsible for the loss of huge amounts of water
- Water is replaced by a tremendous surface water inflow from the Atlantic Ocean (sea level is 15 cm higher at Gibraltar than it is by Lebanon and Israel)
- Water moves east from Gibraltar along the coast of Africa, spreading north

- In eastern Mediterranean, water gets denser because of higher salinity caused by high rates of evaporation (15°C/59°F, and 39.1 ppt salinity)
- This is called Mediterranean Intermediate Water (MIW)
- MIW is very salty and sinks, returning to the Atlantic Ocean as subsurface flow through the Strait of Gibraltar
- At that point MIW is less salty but still dense enough to drop along the continental slope

Mediterranean Sea Circulation

This circulation is typical of closed, restricted basins where evaporation exceeds precipitation

Water circulation is *opposite* to estuarine circulation, and is called Mediterranean Circulation



Chapter 10
part 5

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