Salt Sea and convecton

Presented by
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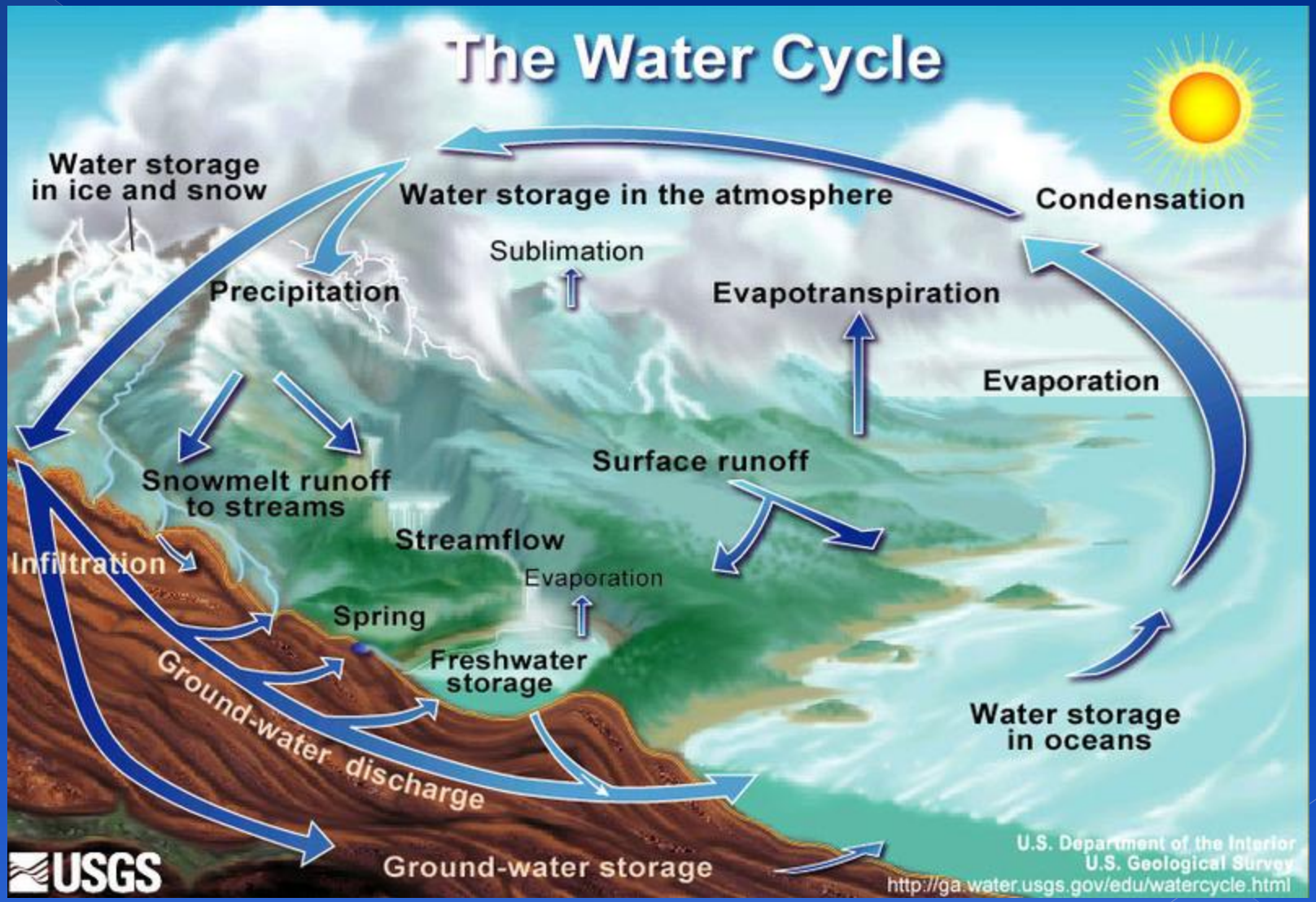

The Water Cycle
Water storage in ice and snow
Water storage in the atmosphere
Condensation
Sublimation
Precipitation
Evapotranspiration
Evaporation
Surface runoff
Snowmelt runoff to streams
Streamflow
Infiltration
Evaporation
Spring
Freshwater storage
Ground-water discharge
Water storage in oceans
Ground-water storage
USGS
U.S. Department of the Interior
U.S. Geological Survey
http://ga.water.usgs.gov/edu/watercycle.html

Salinity

Salinity

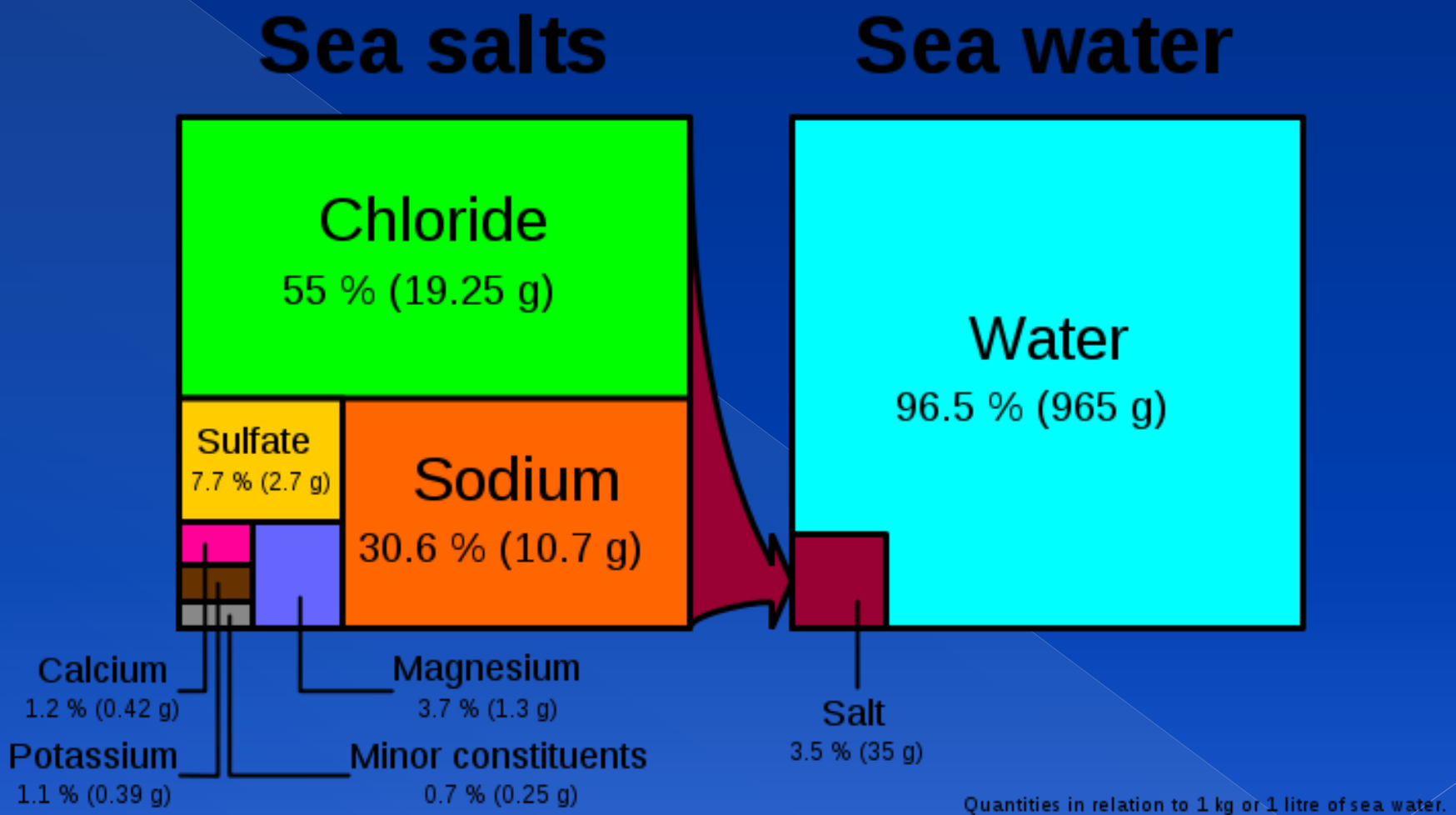
- Salinity is the saltiness or dissolved salt content of a body of water. It is a general term used to describe the levels of different salts such as sodium chloride, magnesium and calcium sulfates, and bicarbonates.

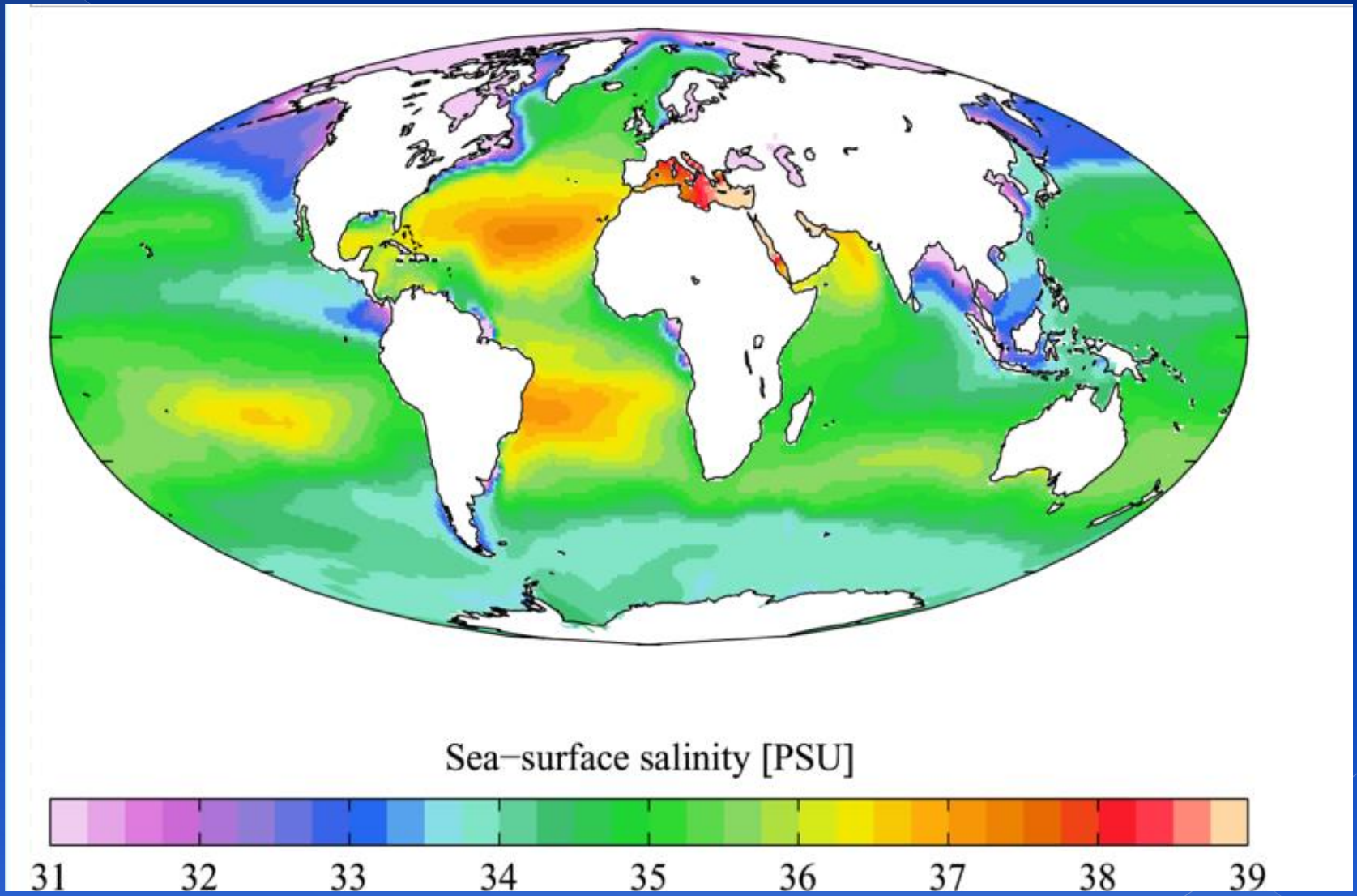
Water salinity			
Fresh water	Brackish water	Saline water	Brine
< 0.05 %	0.05 – 3 %	3 – 5 %	> 5 %
< 0.5 ‰	0.5 – 30 ‰	30 – 50 ‰	> 50 ‰

- The technical term for saltiness in the ocean is *salinity*. In oceanography, it has been traditional to express salinity not as percent, but as parts per thousand ($/_{oo}$), which is approximately grams of salt per kilogram of solution. Other disciplines use chemical analyses of solutions, and thus salinity is frequently reported in mg/L or ppm (parts per million).

Seawater composition (by mass)
(salinity = 35)

Element	Percent	Element	Percent
Oxygen	85.84	Sulfur	0.091
Hydrogen	10.82	Calcium	0.04
Chlorine	1.94	Potassium	0.04
Sodium	1.08	Bromine	0.0067
Magnesium	0.1292	Carbon	0.0028


Sea salts
Sea water
Chloride
55 % (19.25 g)
Sulfate
7.7 % (2.7 g)
Sodium
30.6 % (10.7 g)
Water
96.5 % (965 g)
Calcium
1.2 % (0.42 g)
Potassium
1.1 % (0.39 g)
Magnesium
3.7 % (1.3 g)
Minor constituents
0.7 % (0.25 g)
Salt
3.5 % (35 g)
Quantities in relation to 1 kg or 1 litre of sea water.


Sea−surface salinity [PSU]
31
32
33
34
35
36
37
38
39

Salinity

- Although the vast majority of seawater has a salinity of between 3.1% and 3.8%, seawater is not uniformly saline throughout the world. Where mixing occurs with fresh water runoff from river mouths or near melting glaciers, seawater can be substantially less saline. The most saline open sea is the Red Sea, where high rates of evaporation, low precipitation and river inflow, and confined circulation result in unusually salty water.

Sea water Intrusion

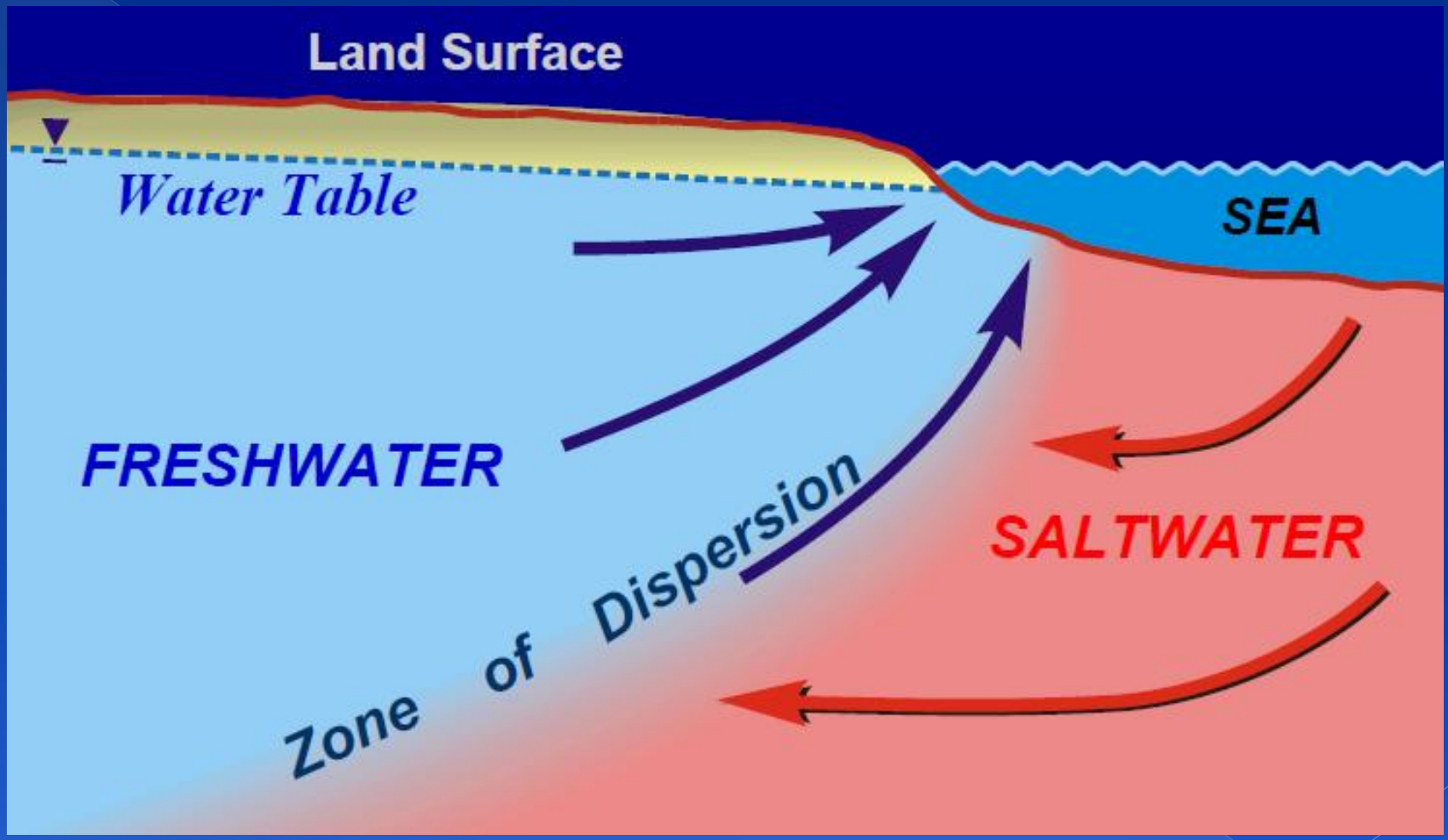
Sea water Intrusion

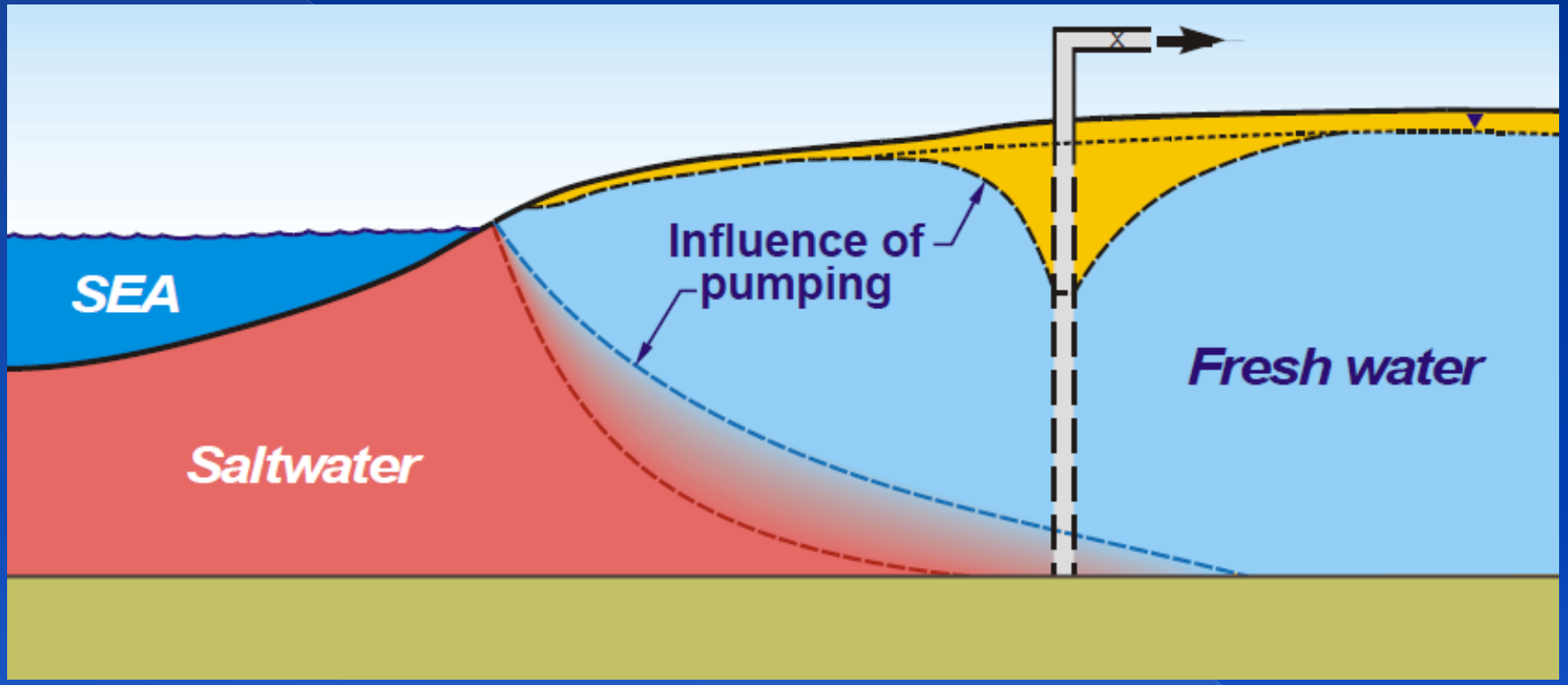
- Seawater intrusion (or saltwater intrusion) is the encroachment of saline waters into zones previously occupied by fresh groundwater.
- Under natural conditions, hydraulic gradients in coastal aquifers are towards the sea and a stable interface between the discharging groundwater and seawater exists, notwithstanding climatic events or sea-level rise.
- Persistent disturbances in the hydraulic equilibrium between the fresh groundwater and denser seawater in aquifers connected to the sea produce movements in the position of the seawater-freshwater interface, which can lead to degradation of freshwater resources.
- The impacts of seawater intrusion are widespread, and have lead to significant losses in potable water supplies and in agricultural production.

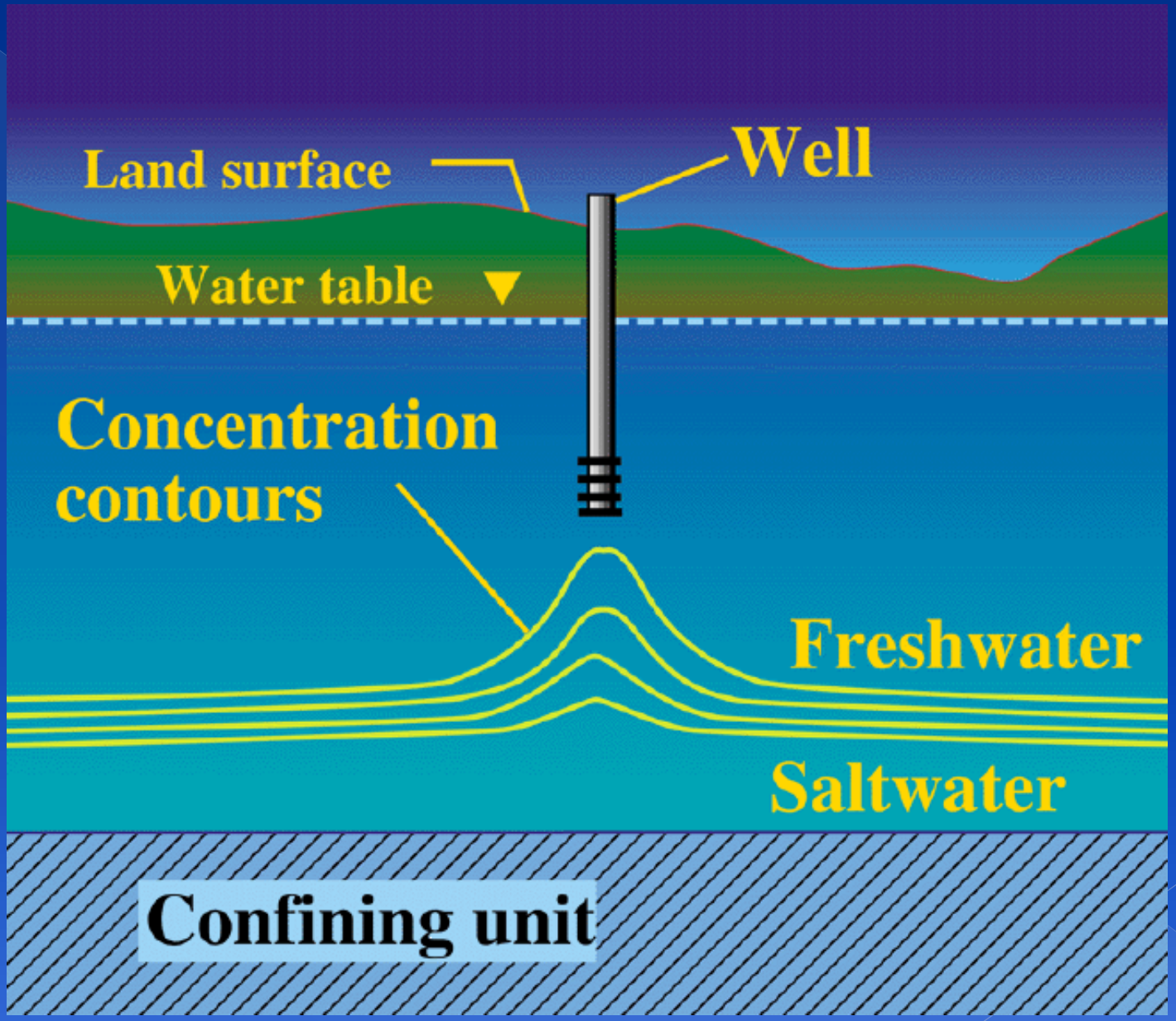
Sea water Intrusion

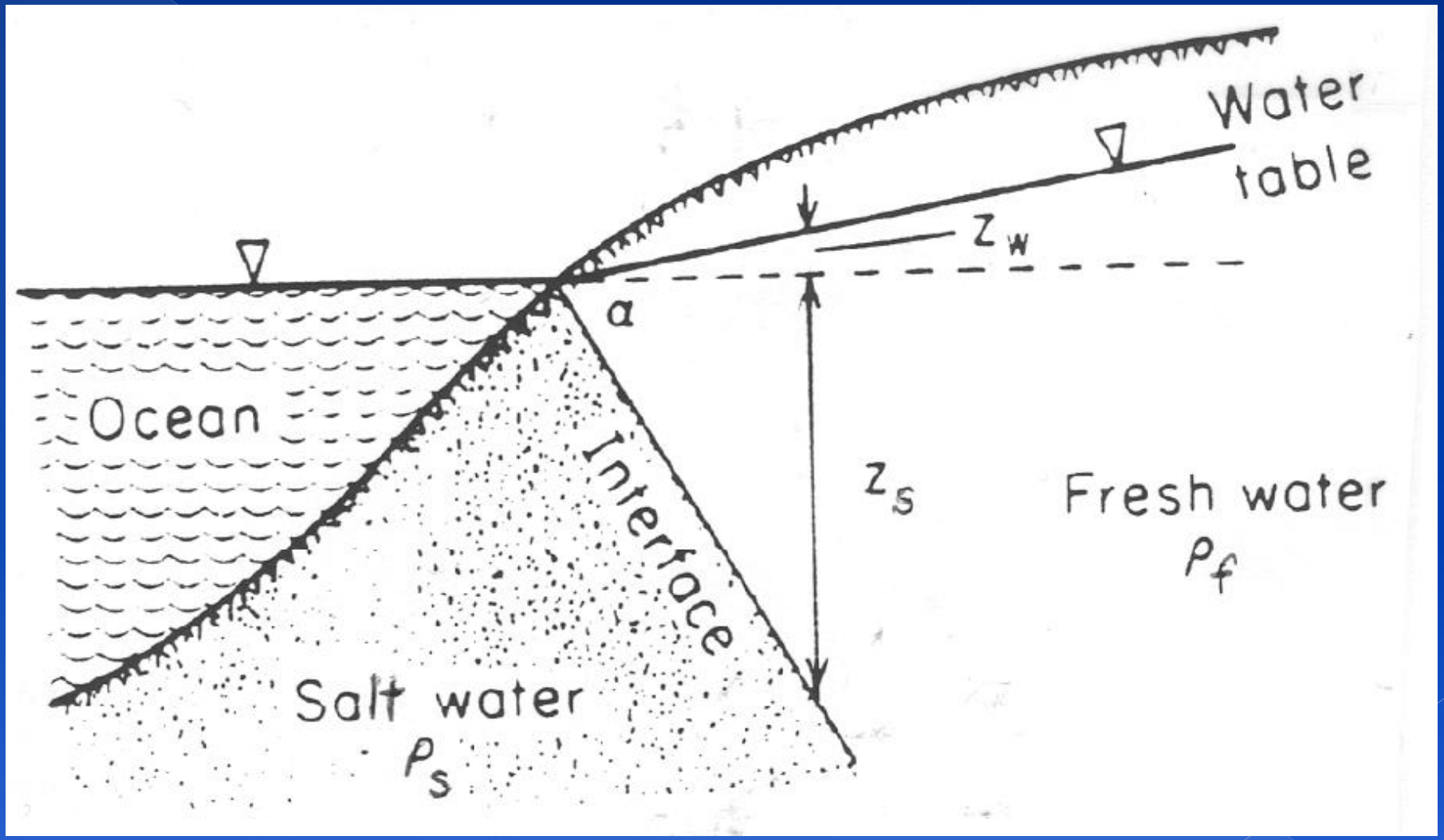
- In unconfined coastal aquifers, there is groundwater flow occurring in both the fresh zone and the saline zone . Fresh water is flowing upward to discharge near the shoreline, and there is a cyclic flow in the salty water near the interface. Many studies assume that there is a sharp interface between fresh water and saline water.

- However, the saltwater-freshwater interface can be studied using dispersion and mass-transport theory, the mathematical treatment involved is often very complex and will not be discussed in these notes. The zone of dispersion is often thin with respect to the overall thickness of the freshwater lens. Some solutions do however exist for the problem of a moving interface


Land Surface
Water Table
SEA
FRESHWATER
SALTWATER
Zone of Dispersion


SEA
Influence of
pumping
Fresh water
Saltwater


Land surface
Well
Water table
Concentration contours
Freshwater
Saltwater
Confining unit


Water table
z_w
a
Ocean
Interface
z_s
Fresh water
ρ_f
Salt water
ρ_s

Transgression-Regression salinisation of coastal aquifers

Transgression-Regression salinisation of coastal aquifers

- Tidal forcing, seasonal changes in recharge and groundwater abstraction are key factors responsible for variability and change in coastal groundwater systems. These drivers act on human time scales. However, when viewed on longer time scales from centuries to millions of years, coastal zones are even more dynamic.

- Sea-level change, erosion and sedimentation have caused coastlines to shift back (i.e., seaward: regression) and forth (i.e., landward: transgression) over distances of up to several hundreds of kilometres.

- Groundwater systems responded to these conditions by adjustment of flow fields and redistribution of fresh and saline water.

Transgression-Regression salinisation of coastal aquifers

- It is essential to realize that the textbook conception of the fresh and saline groundwater distribution, which is classically conceived of as a fresh water lens overlying a wedge of saline groundwater, is not always encountered in real field settings due to the dynamic nature of shorelines.

- **The most conspicuous manifestations of transient effects are offshore occurrences of fresh groundwater and onshore (land based) occurrences of salt water.**

Offshore fresh and brackish paleo-groundwater

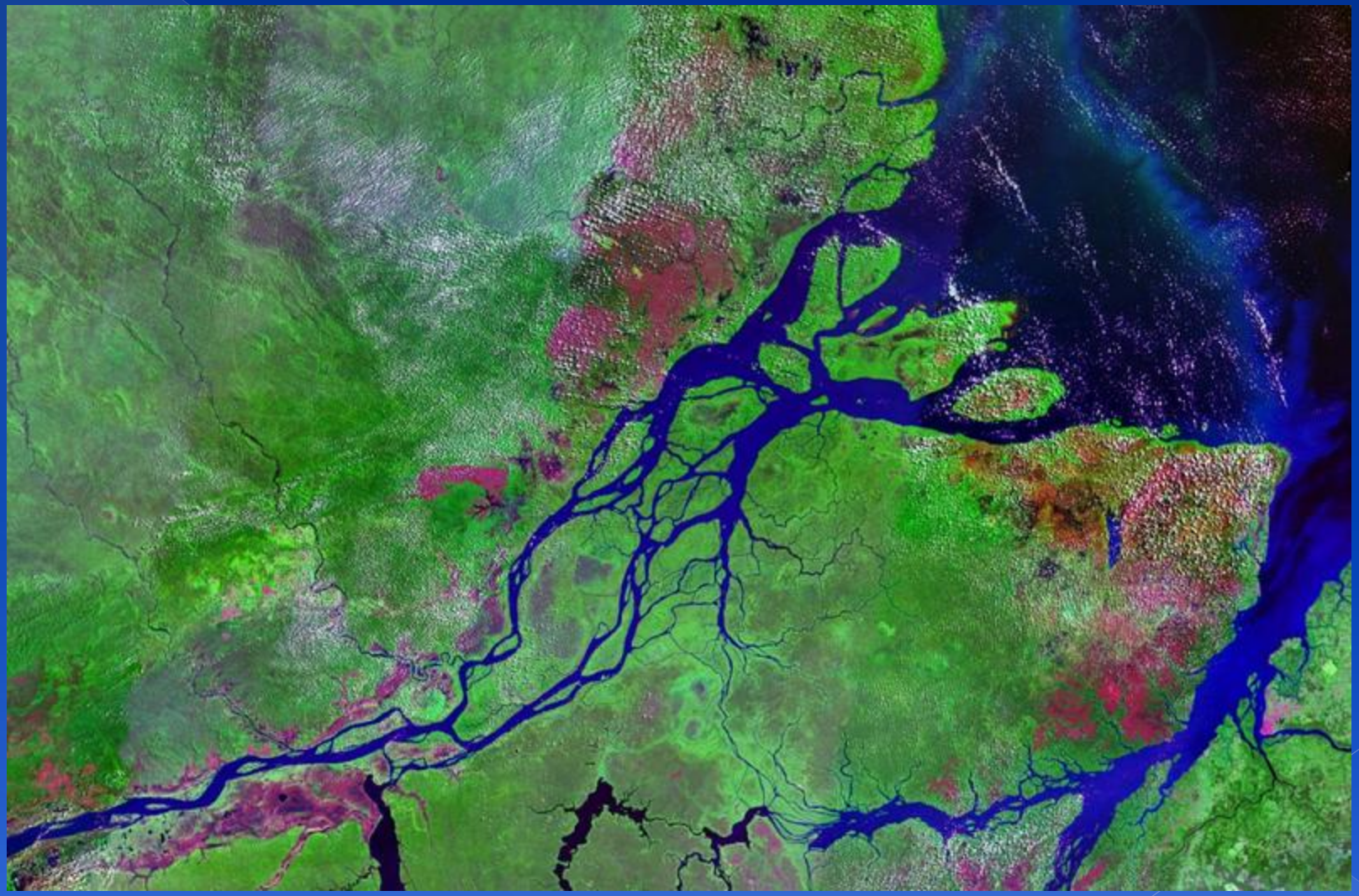
Offshore fresh and brackish paleo-groundwater

- **Brackish water** is water that has more salinity than fresh water, but not as much as sea water. It may result from mixing of seawater with fresh water, as in estuauries, or it may occur in brackish fossil aquifiers.

- Technically, brackish water contains between 0.5 and 30 grams of salt per litre—more often expressed as 0.5 to 30 parts per thousand (ppt or ‰). Thus, *brackish* covers a range of salinity regimes and is not considered a precisely defined condition. It is characteristic of many brackish surface waters that their salinity can vary considerably over space and/or time.

Water salinity based on dissolved salts in parts per thousand (ppt)			
Fresh water	Brackish water	Saline water	Brine
< 0.5	0.5 – 30	30 – 50	> 50

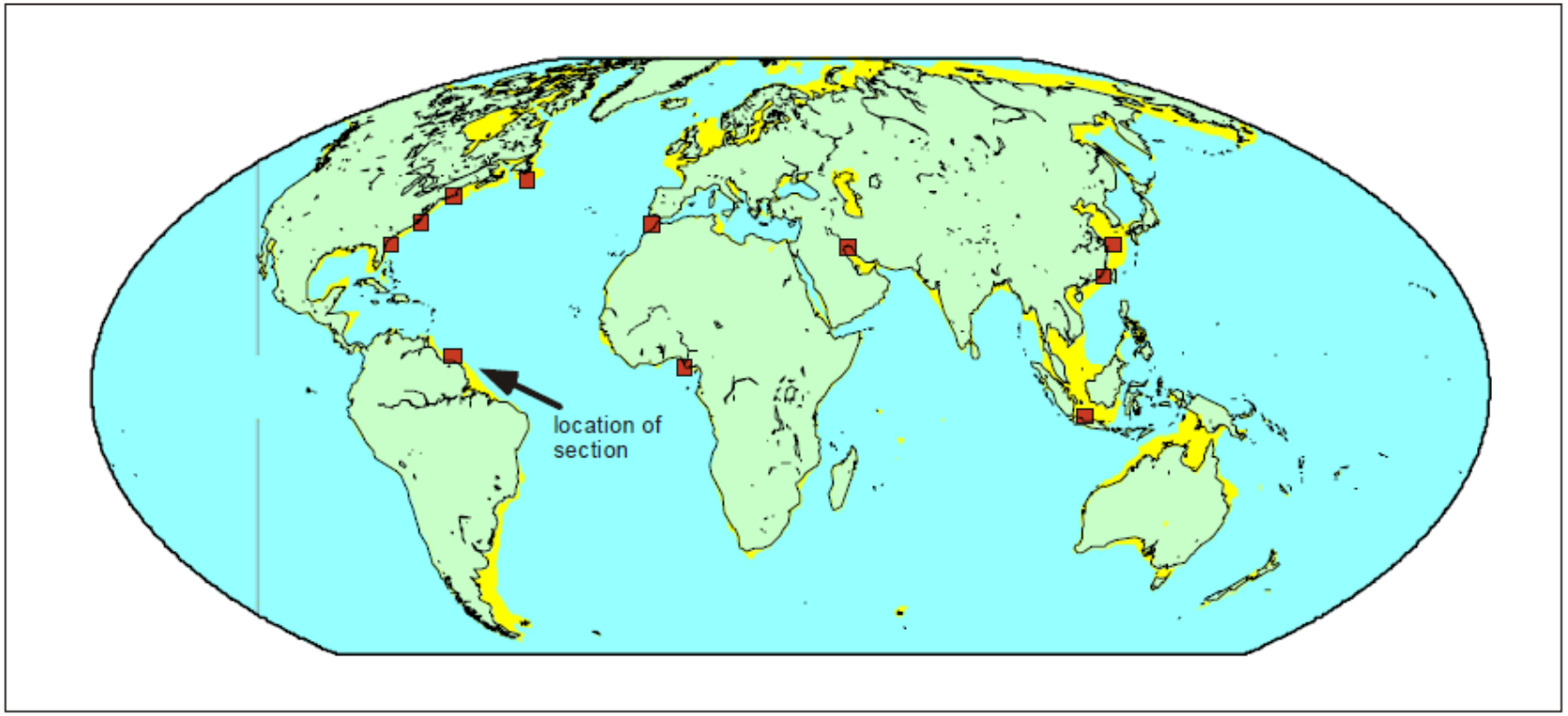
Mouths of amazon



Offshore fresh and brackish paleo-groundwater

- Evidence suggests that sub-seafloor fresh and brackish groundwater are common features of continental shelves and shallow seas around the world.
- E.g., Dutch sector of the North Sea [Post et al., 2000] have shown that groundwater with salt contents between 1 and 50% of seawater occur up to 150 km from the present coastline and at depths up to 400 m below the seafloor.
- In many instances these waters occur too far offshore to be explained by active sub-sea outflow of fresh water due to topographic drive.
- Moreover, lowest salinities often occur at substantial depths beneath the seafloor and are overlain by more saline pore waters, suggesting absence of discharge pathways. These waters therefore are considered paleo-groundwaters that were emplaced during glacial periods with low sea level. During subsequent periods of sea-level rise, salinization was apparently slow enough to allow relics of these fresh waters to be retained.

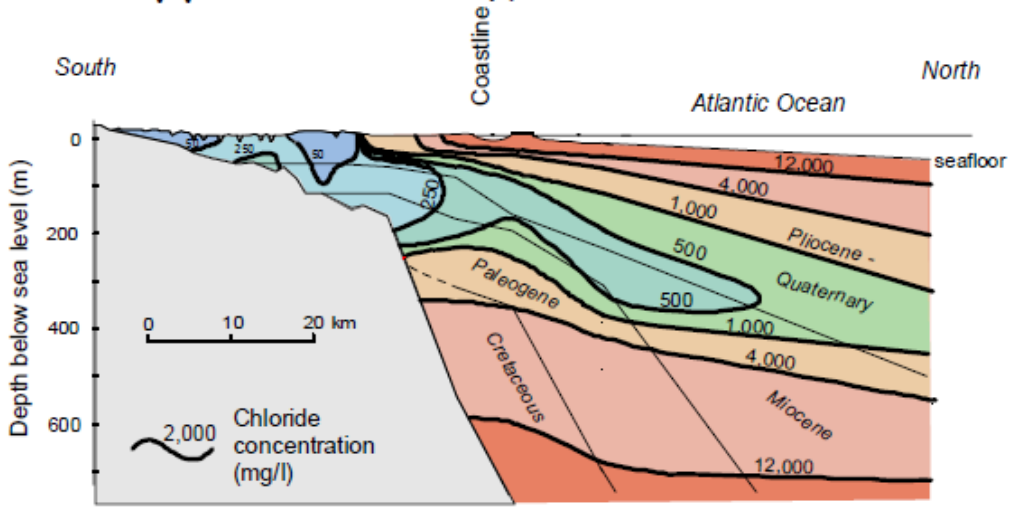
Known occurrences of offshore brackish groundwater

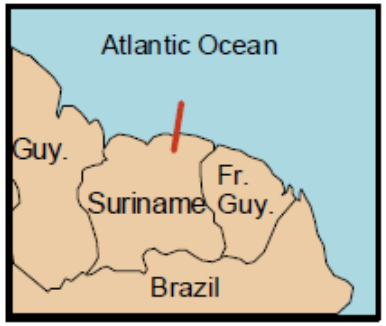


Formerly exposed shelf

Inferred occurrences of offshore fresh to brackish paleo-groundwater (modified from Groen, 2002)

Offshore brackish water related to low sea levels?





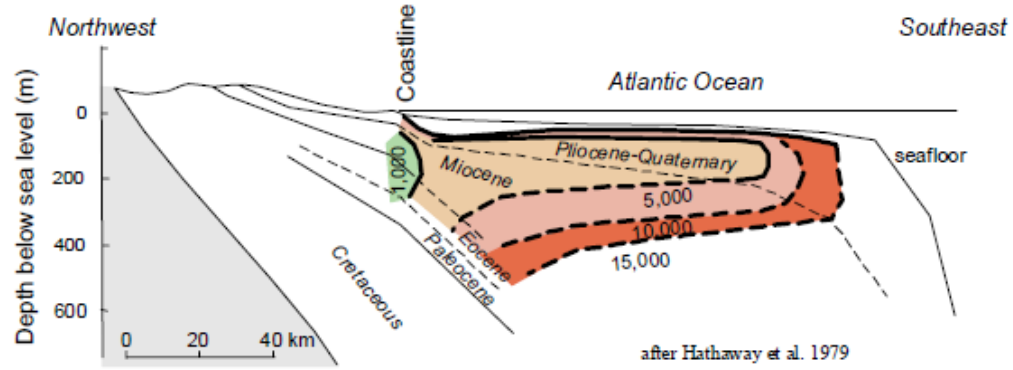
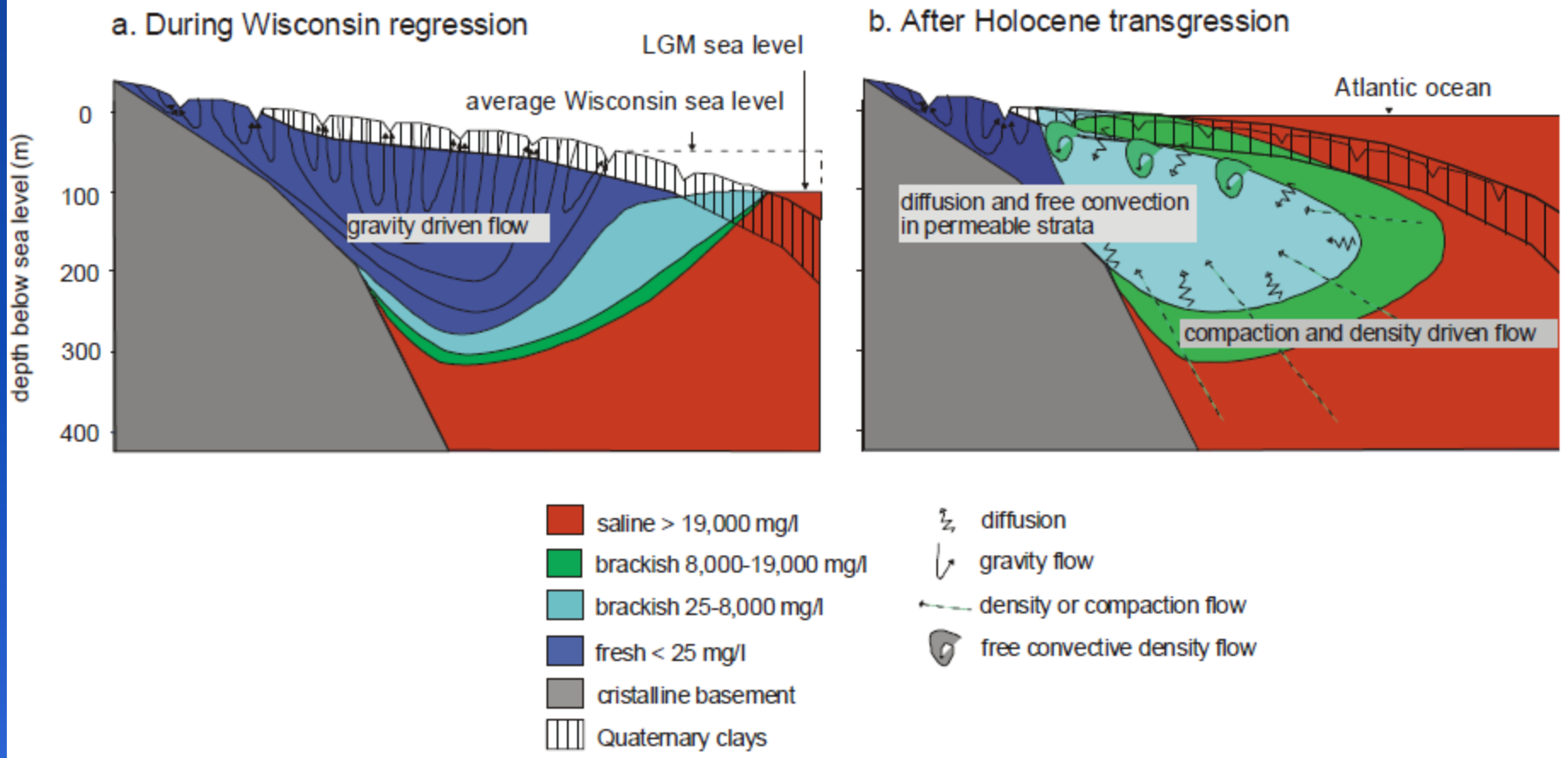


Figure 1. Examples of relatively fresh groundwater extending far into the offshore. (top) Continental margin of Suriname, South America [modified after *Groen et al.* 2000]. (bottom) U.S. Atlantic continental margin off New Jersey [modified after *Hathaway et al.*, 1979]. Thick lines denote contours of chloride concentrations (mg/L). Seawater chlorinity is typically ~19,000 mg/L.

Conceptual paleohydrogeological evolution



Onshore saline groundwater

Onshore saline groundwater

- In many flat coastal and delta areas the coastline during the recent geologic past was located further inland than today. As a result, vast quantities of saline water were retained in the subsurface after the sea level retreated. Such occurrences of saline groundwater are sometimes erroneously attributed to seawater intrusion, i.e., the inland movement of seawater due to aquifer over-exploitation.

- High salinities are maintained for centuries to millennia, or sometimes even longer, when the presence of low-permeability deposits prevents flushing by meteoric water .

- Rapid salinization due to convective sinking of seawater plumes occurs when the ransgression is over a high-permeability substrate. This process is responsible for the occurrence of saline groundwater up to depths of 400 m in the coastal area of the Netherlands.

Salt lakes and saline disposal basins

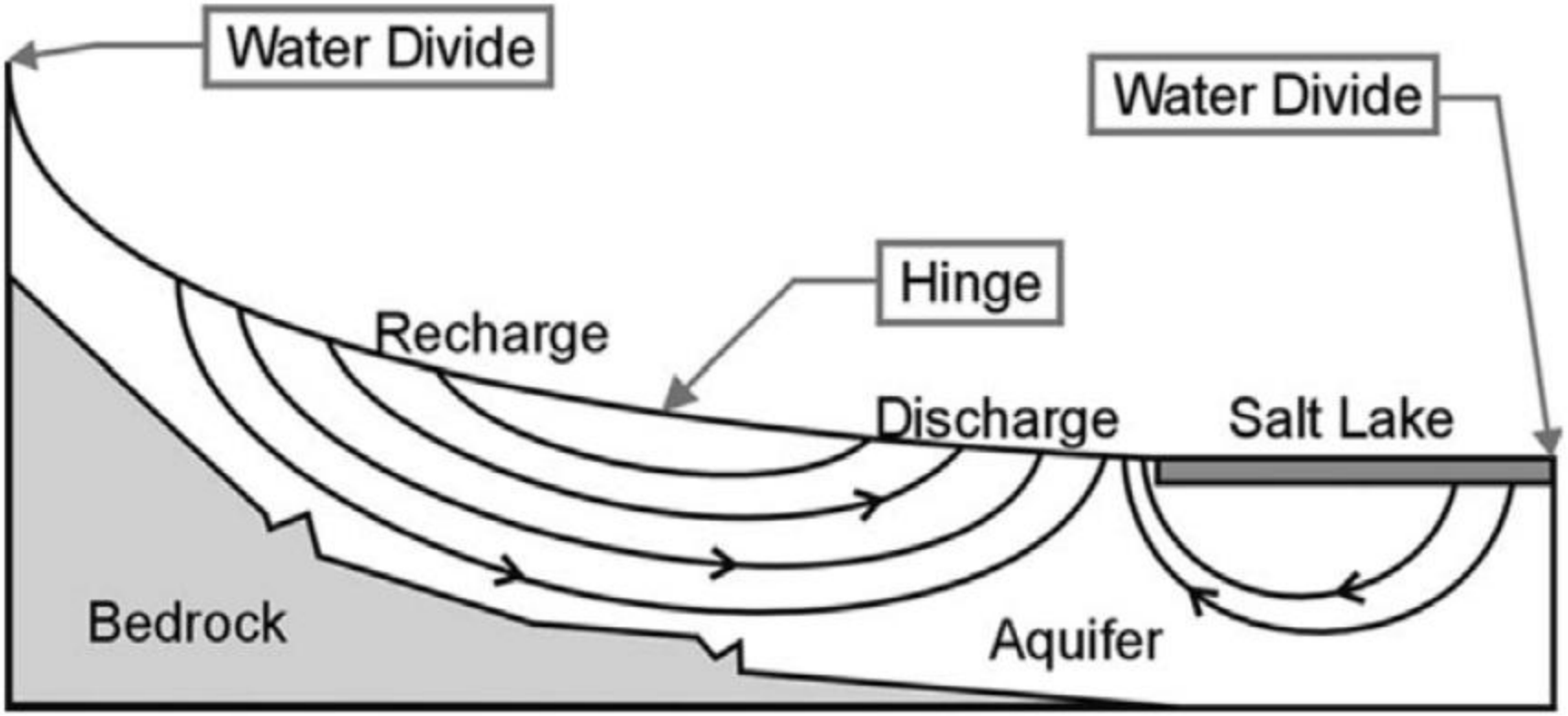


Figure 1. Schematic view of steady groundwater flow in the vicinity of salt lakes.