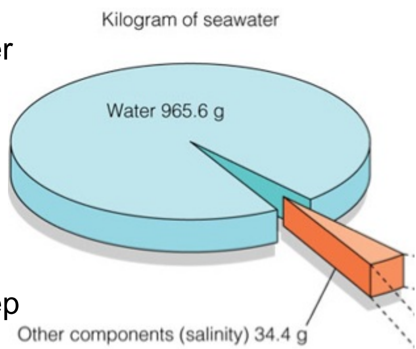


What is Sea Salt?

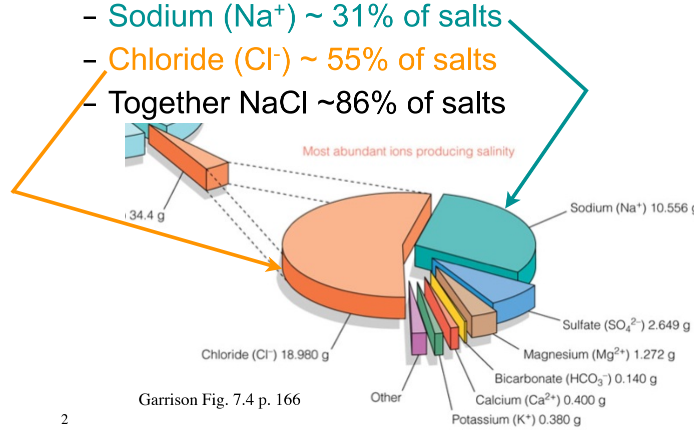
- Water
- Salts
  - Salinity = grams salts per kilogram sea water
  - Average = 35 g/kg = 3.5%
- World ocean has 5 x 10^{15} (quadrillion) kg salts
  - Cover Earth 45 m deep



Garrison Fig. 7.4 p. 166

What are Sea Salts?

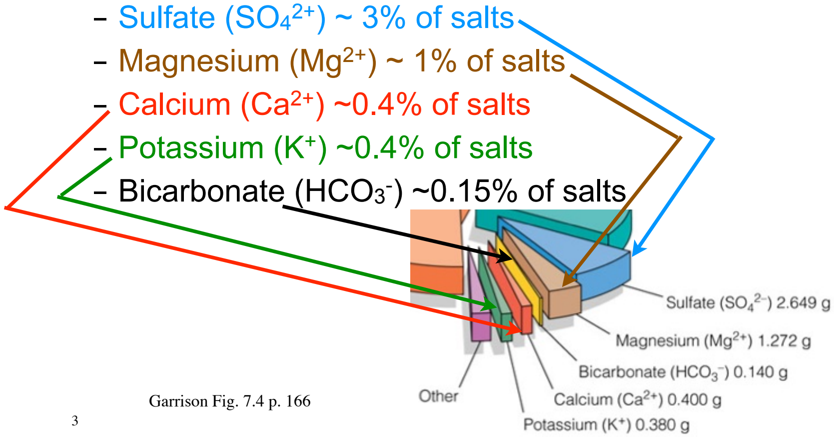
- Mostly what you already know
  - Sodium (Na^+) ~ 31% of salts
  - Chloride (Cl^-) ~ 55% of salts
  - Together NaCl ~86% of salts



Garrison Fig. 7.4 p. 166

What are Sea Salts?

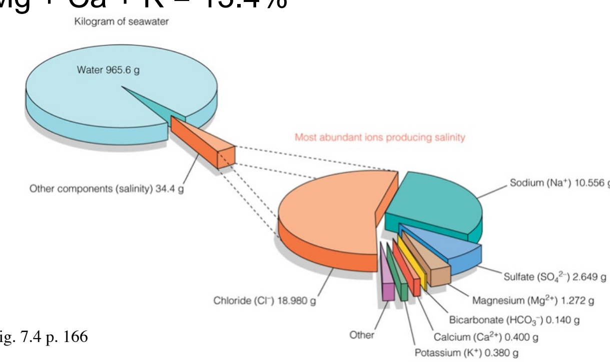
- Some other familiar dissolved chemicals
  - Sulfate (SO_4^{2+}) ~ 3% of salts
  - Magnesium (Mg^{2+}) ~ 1% of salts
  - Calcium (Ca^{2+}) ~0.4% of salts
  - Potassium (K^+) ~0.4% of salts
  - Bicarbonate (HCO_3^-) ~0.15% of salts



Garrison Fig. 7.4 p. 166

What are Sea Salts?

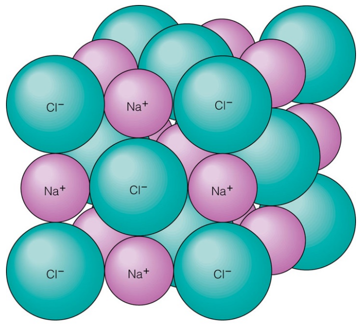
- Big 6 account for 99.4% of all sea salts
  - Na + Cl = 86%
  - SO_4 + Mg + Ca + K = 13.4%



Garrison Fig. 7.4 p. 166

Chemical Nature of Sea Salts

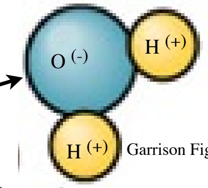
- Salts are molecules that break apart easily in water solution
  - Atoms separate from each other
  - Form ions
    - Electrically charged atoms
    - Gain or lose one or more electrons while in solution
  - NaCl ionizes to form:
    - Na+ (loses the electron)
    - Cl- (gains the electron)
  - Only occurs with certain combinations of atoms



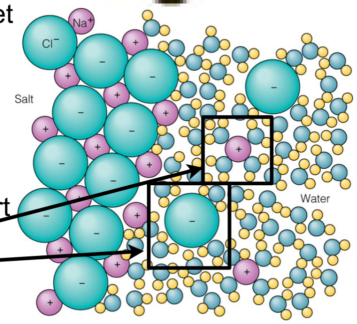
Garrison Fig. 7.2 p. 164

Chemical Nature of Sea Salts

- Ionic molecules dissolve easily in water
  - Water molecule H_2O has electrical polarity
    - Like a v-shaped bar magnet
    - Oxygen more negative
    - Hydrogen more positive
  - Water molecules attract salt ions
    - Help pull Na & Cl ions apart
      - O^- attracted to Na^+
      - H^+ attracted to Cl^-



Garrison Fig. 7.3 p. 164



Salts in the Sea

- Solubility affects fate of chemicals when they enter the ocean
  - High solubility
    - Accumulates at high concentrations in sea water
    - Remains in the ocean a long time
  - Low solubility
    - Low concentrations in sea water
    - Leaves the ocean relatively sooner
  - NaCl a very soluble salt
    - But only a salt when it is solid
    - Dissolves to yield two most abundant ions
    - Remains in the oceans for millions of years

Why the Sea is Salt

- The real question:
  - Why isn't the sea much saltier than it is?
- Total mass of dissolved solids entering the oceans each year
  - 0.000005 of one percent ($5*10^{-8}$) of the total mass of dissolved solids already in the oceans
- How long until the oceans would reach their present salinity?
  - "Only" 20 million years
- But sediments indicate constant ocean salinity
  - Last 1.5 billion years

Why the Sea is Salt

- The real question:
  - Why isn't the sea much saltier than it is?
- Something is removing salts from the oceans
  - Ocean chemistry is at equilibrium
  - Inputs are equaled by outputs
  - Sources = Sinks
    - Sink= a removal location or process
  - Residence time = how long salt stays in ocean

Source for salt X → **Residence time in the oceans** / At equilibrium, sink = source → "Sink" for salt X

Sources & Sinks

- Each type of ion has a different set of sources & sinks

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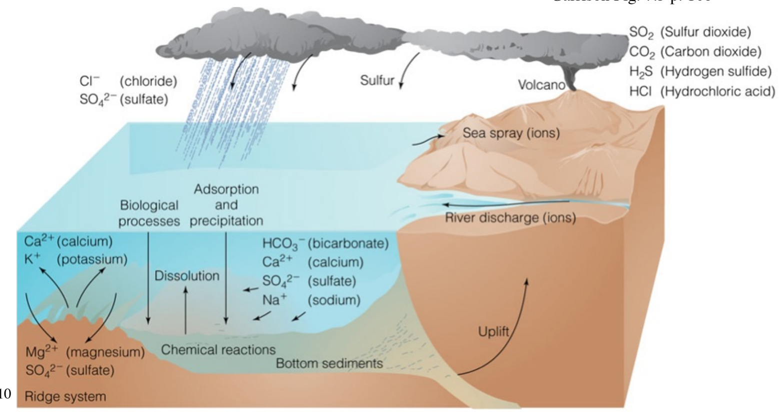
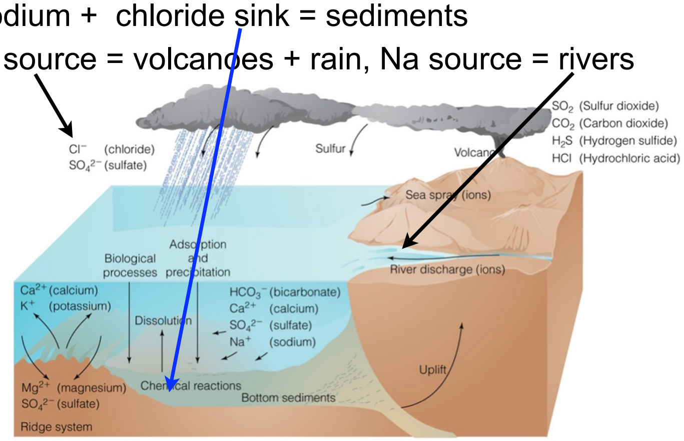


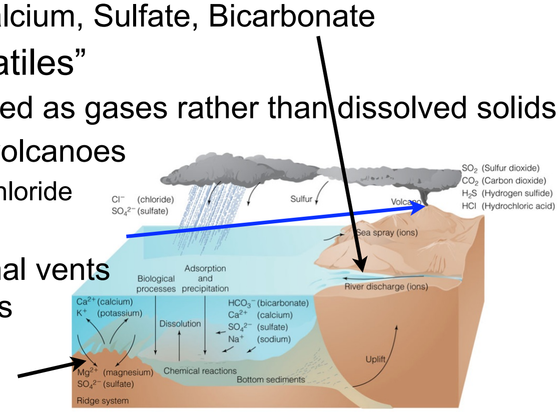
Sources & Sinks

- Example: Na & Cl
  - Sodium + chloride sink = sediments
  - Cl source = volcanoes + rain, Na source = rivers



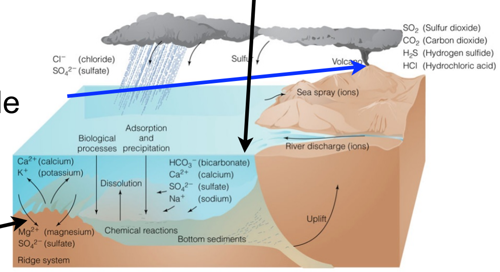
Sources

- Erosion of land, transport by rivers
  - Sodium, Calcium, Sulfate, Bicarbonate
- "Excess volatiles"
  - Ions delivered as gases rather than dissolved solids
  - Terrestrial volcanoes
    - Sulfate, Chloride
    - Carbon
  - Hydrothermal vents at rift valleys
    - Calcium
    - Potassium



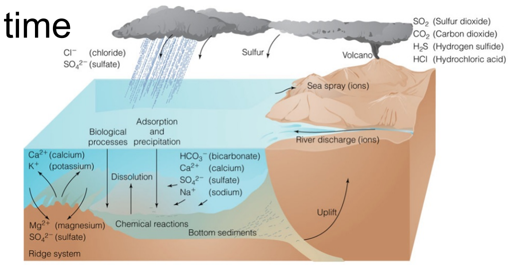
Sinks

- Inorganic (non-biogenous) sediments
  - Sodium, Calcium, Sulfate, Bicarbonate
- Organic (biogenous) sediments
  - Calcium, carbonate
  - Silicon
- Evaporation
  - Sodium, Chloride
- Hydrothermal vents
  - Magnesium
  - Sulfate



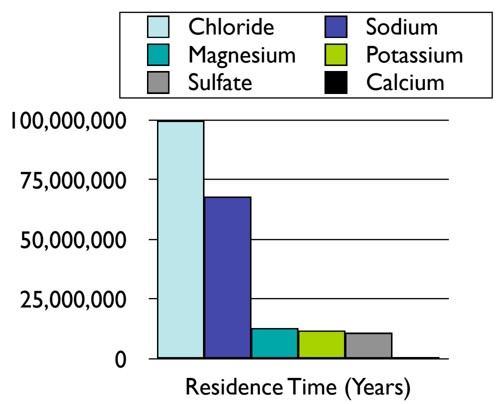
Residence Time

- Residence time (years) =
  - Amount in ocean ÷ amount entering/leaving per year
- Long residence time
  - Large amount in ocean
  - Very soluble
- Short residence time
  - Small amount in ocean
  - Poorly soluble



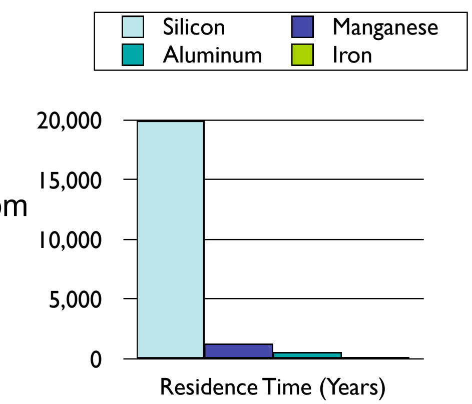
Residence Time

- Residence time (years) =
  - Amount in ocean ÷ amount entering/leaving per year
- Long residence
  - Large amount in ocean
  - Very soluble
  - The Big 6 ions



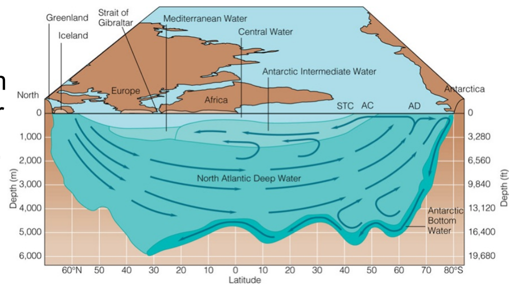
Residence Time

- Short residence
  - Small amount in ocean
  - Poorly soluble
- Sources
  - Erosion & rivers
- Sinks: sediments
  - Silicon part of diatom skeletons
  - Manganese in Mn nodules
  - Aluminum in clay



Dissolved Gases

- Also have sources & sinks
  - Both inorganic (non-living) & organic (living)
  - Inorganic:
    - Gases from atmosphere dissolve in sea water
    - Main effect is on surface waters
    - Global density circulation transports them into deep water
    - Sinking of cold, salty water at polar latitudes

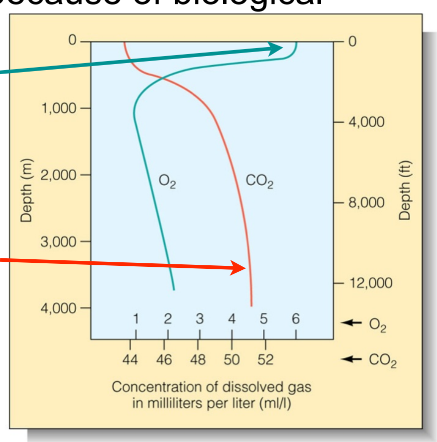


Important Gases in the Ocean

- Nitrogen (N_2)
  - "Fixed" nitrogen (NO_3, NO_2, NH_4) an essential nutrient for photosynthesis
  - "Nitrogen fixing" bacteria convert N_2 gas to fixed N
    - Make it available for biological production
- Oxygen (O_2)
  - Generated by photosynthesis
  - Consumed by respiration & decay
- Carbon dioxide (CO_2)
  - Generated by respiration & decay
  - Consumed by photosynthesis

Oxygen & Carbon Dioxide

- Change with depth because of biological activity
  - O_2 maximum at surface
    - Light available for photosynthesis
    - Consumes CO_2
  - CO_2 maximum deep in water
    - Decomposition of sinking dead material
    - Consumes O_2

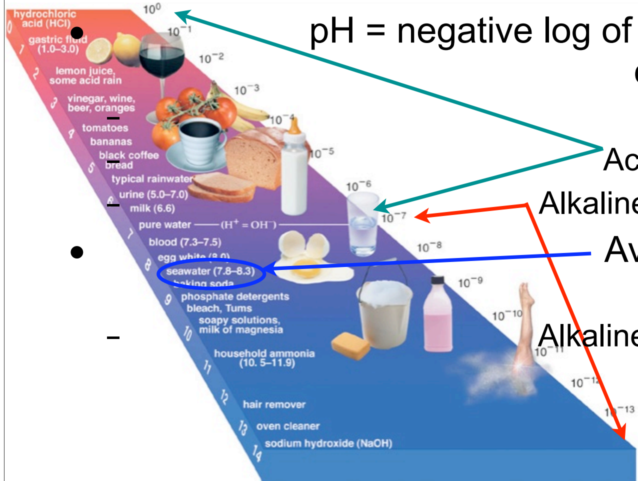


Garrison Fig. 7.8 p. 172

Carbon Dioxide & Acidity

- CO_2 part of the complex dissolved carbonate system
- Key functions
  - Controls acidity & alkalinity of sea water
    - Affects many other chemical & biological reactions
  - Source of skeletal material for numerous organisms
    - Calcium carbonate $CaCO_3$
    - Calcareous plankton
    - Bottom-living shellfish: clams, crabs, etc.
    - Coral reefs
  - Multiple interchangeable forms of combined carbon

Carbon Dioxide & Acidity

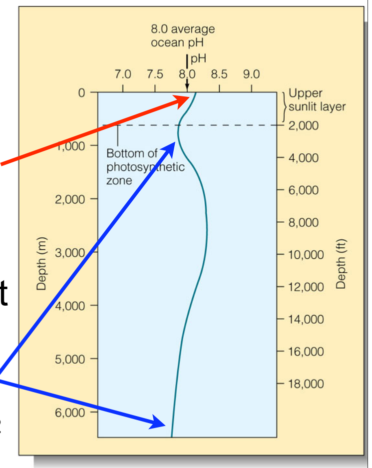


- pH = negative log of hydrogen ion concentration
  - Neutral = 7
  - Acid = less than 7
  - Alkaline = more than 7
- Average acidity of ocean ~8
  - Alkaline: range 7.8-8.3

Garrison Fig. 7.9 p. 172

Carbon Dioxide & Acidity

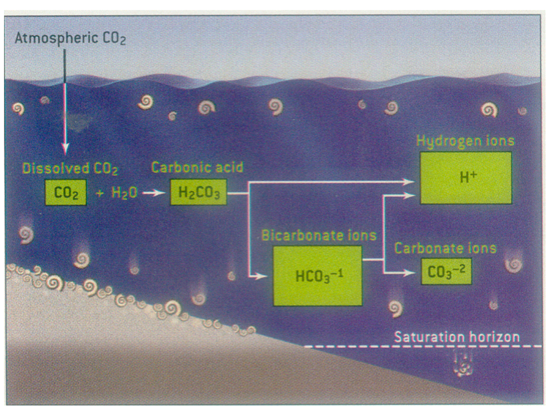
- pH always slightly alkaline (>7)
- pH higher (more alkaline) at surface
  - Photosynthesis consumes CO_2
- pH lower (less alkaline) at bottom of lighted zone & in deep sea
  - Respiration generates CO_2
  - $CaCO_3$ skeletons dissolve



Garrison Fig. 7.12 p. 174

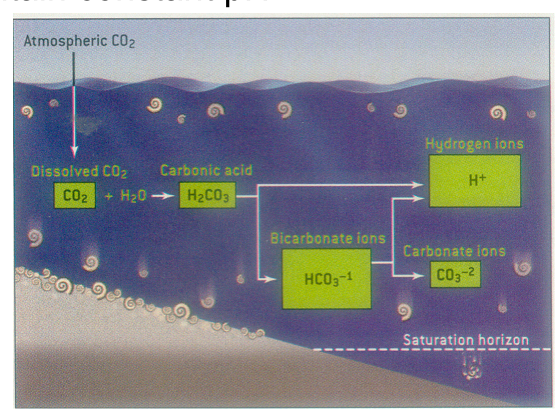
Carbon Dioxide in Sea Water

- CO_2 + water H_2O gives carbonic acid H_2CO_3
  - H_2CO_3 splits
    - HCO_3^- & H^+
  - HCO_3^- splits
    - CO_3^{-2} & H^+
- 5 C species in equilibrium
  - Buffering
  - Proportions shift to keep pH constant



Carbon Dioxide Buffering

- Proportions of CO_2, H_2CO_3, HCO_3^-, CO_3^{-2}, H^+ shift to maintain constant pH
  - Reactions proceed in either direction
- Add CO_2
  - CO_3^{-2} & H^+ recombine
- Add CO_3^{-2}
  - More H_2CO_3 splits



Carbon Dioxide Buffering

- Why does buffering of pH matter?
  - Some biochemical reactions sensitive to pH
  - Major example: formation of calcium carbonate $CaCO_3$ skeletons
    - Calcareous plankton
    - Bottom-living shellfish: clams, crabs, etc.
    - Coral reef
- Ocean pH currently decreasing
  - Increasing atmospheric CO_2
  - Mostly decreasing at surface
  - More difficult to form $CaCO_3$ skeletons

Conservative Constituents

- Some dissolved constituents of sea water are biologically active & others are not
  - Conservative constituents not biologically active
    - Maintain a constant ratio to total salinity
    - Na, Cl, Mg, K, SO_4
  - Nonconservative constituents are biologically active
    - Ratio to total salinity varies depending on biological use
    - Ca, CO_2 system members, O_2, nutrients
- "Principle of Constant Proportions"
  - Can calculate concentration of one conservative ion from any other
    - Measure salinity from Cl^- alone ("Chlorinity")

Nutrients

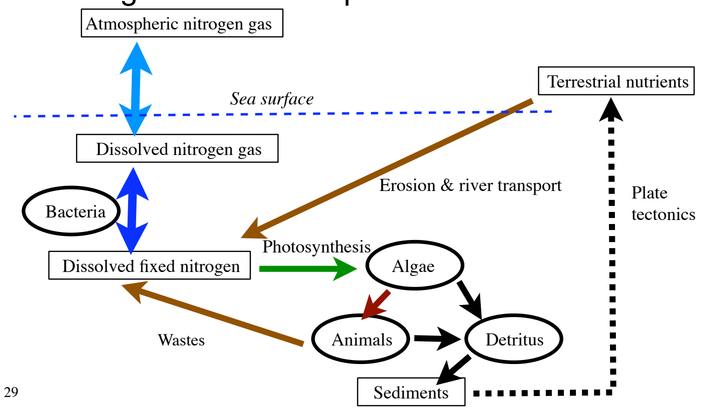
- Primary production = conversion of non-living to living material
  - Photosynthesis conducted by plants, algae, bacteria
  - Chemosynthesis conducted by bacteria, archaea
- Marine photosynthesizers require same nutrients as land plants
  - Fertilizers: Nitrogen N, phosphorus P, potassium K
    - Plenty of K in sea water (1 of the Big 6)
      - ~0.4 g/kg
    - N & P are present in very small amounts
      - ~0.00001 g/kg (~100-500 micrograms/kg, parts/billion)

Marine Nutrients

- Marine photosynthesizers require same nutrients as land plants
  - Also silicon for diatom skeletons
    - ~0.003 g/kg (~3000 micrograms/kg)
  - N, P, Si the "macronutrients"
  - Also "micronutrients"
    - Order of magnitude less abundant (~10 micrograms/kg)
    - Iron, other trace metals, vitamins
- Supply of these nutrients limits primary production under some conditions
  - Often depleted for photosynthesis at the surface

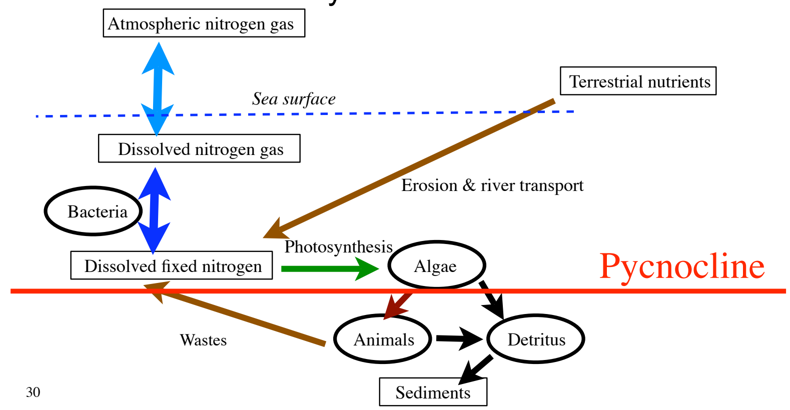
Nutrient Cycles

- Garrison has very complex diagrams
  - Nitrogen as an example



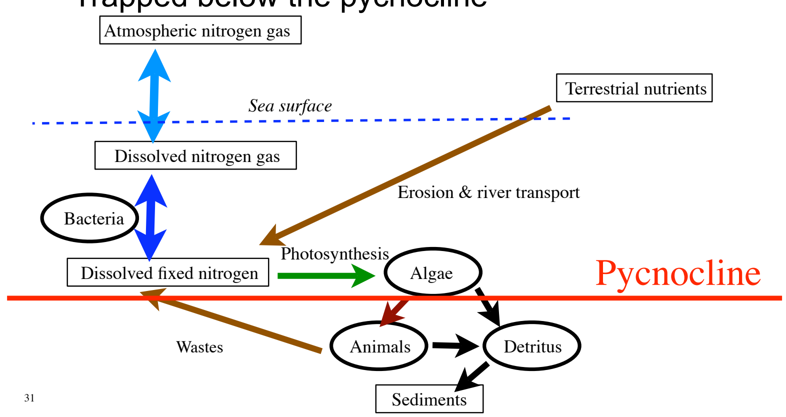
Nutrient Depletion

- 1 more critical factor for biological production
  - The oceans are layered



Nutrient Depletion

- Organic matter sinks to deep water & bottom
  - Trapped below the pycnocline



Nutrient Depletion

- What processes return nutrients to surface?
  - Not pictured here: Upwelling & vertical mixing