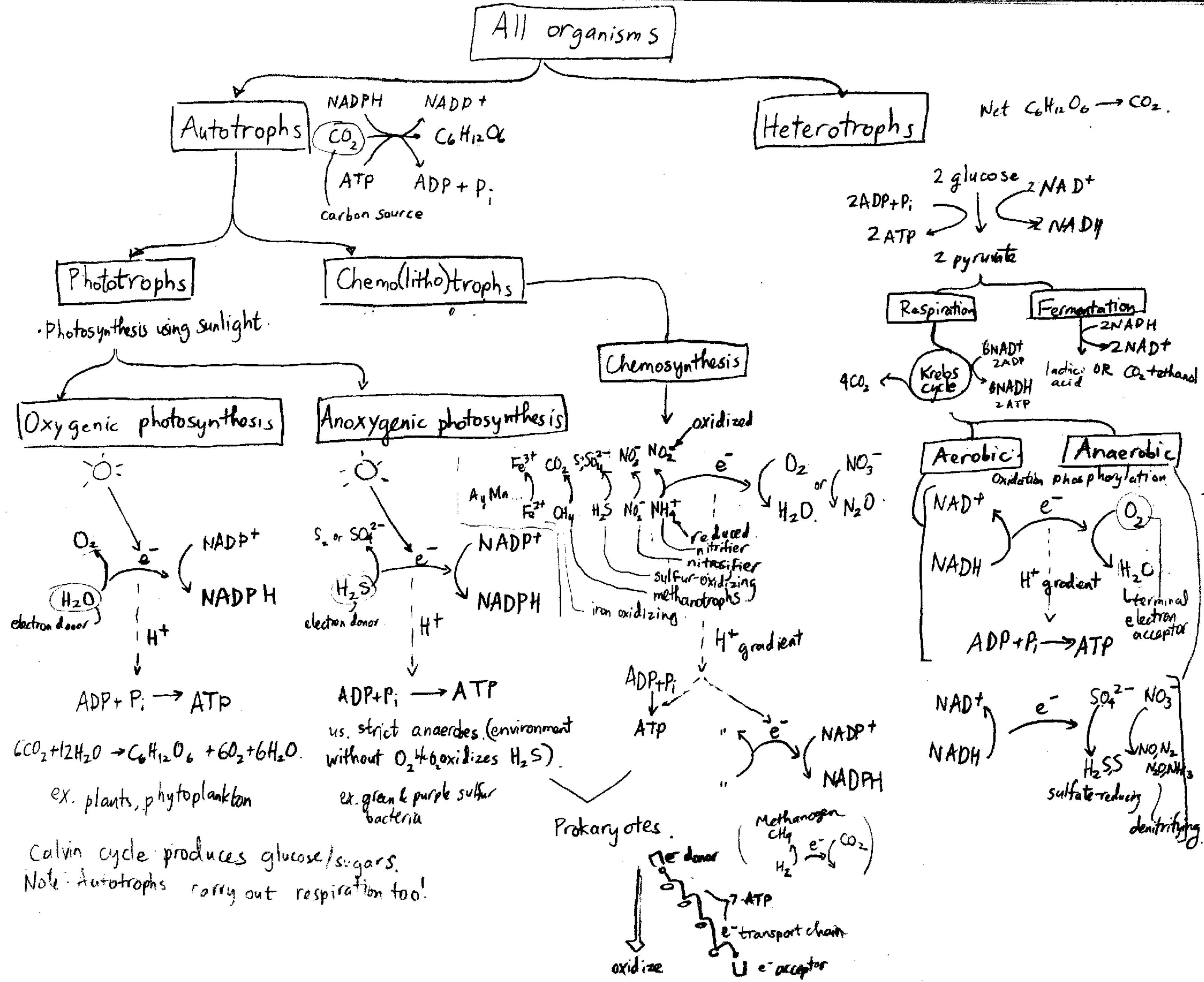
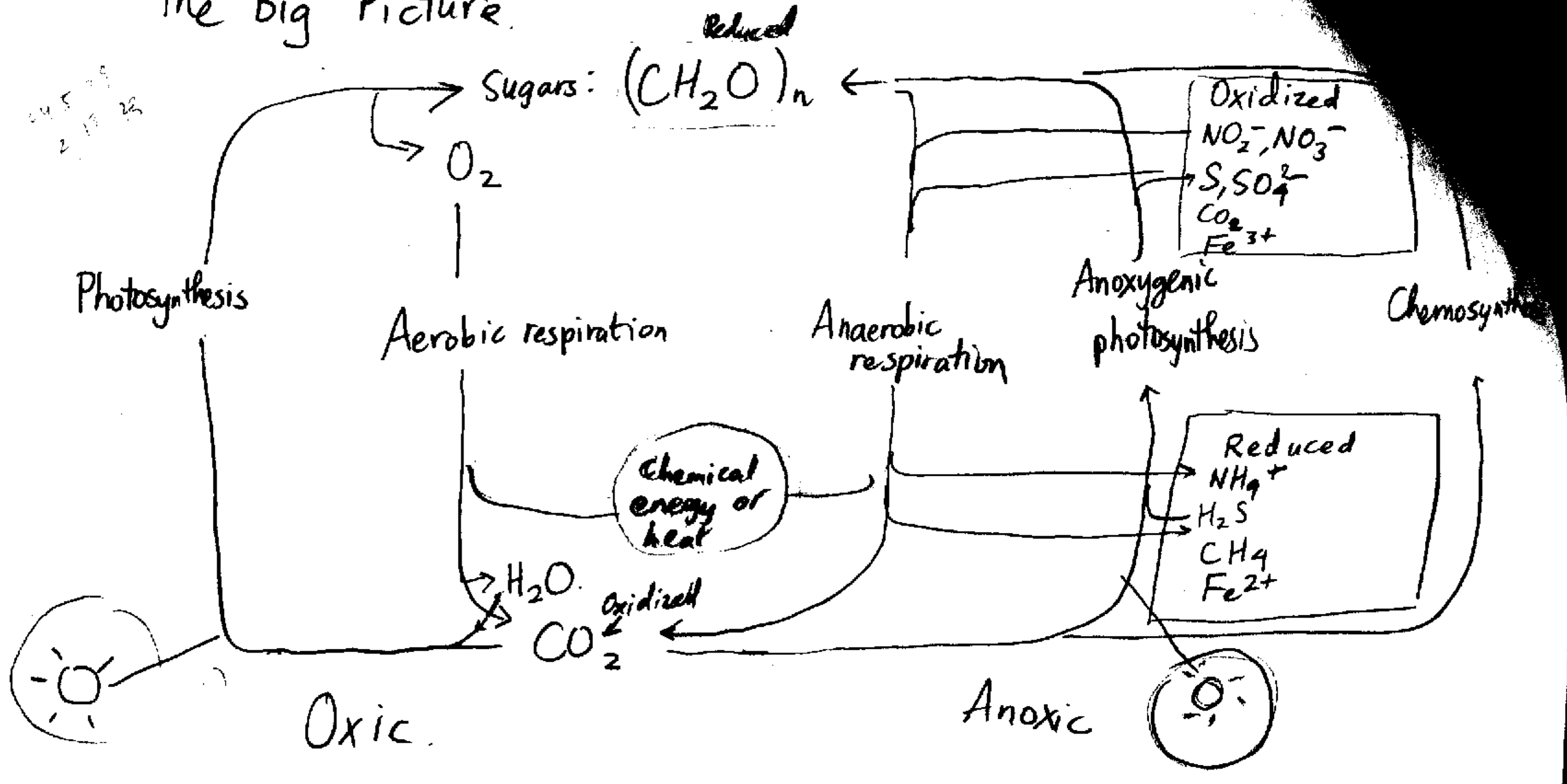
5-1 Metabolism – How to be Alive



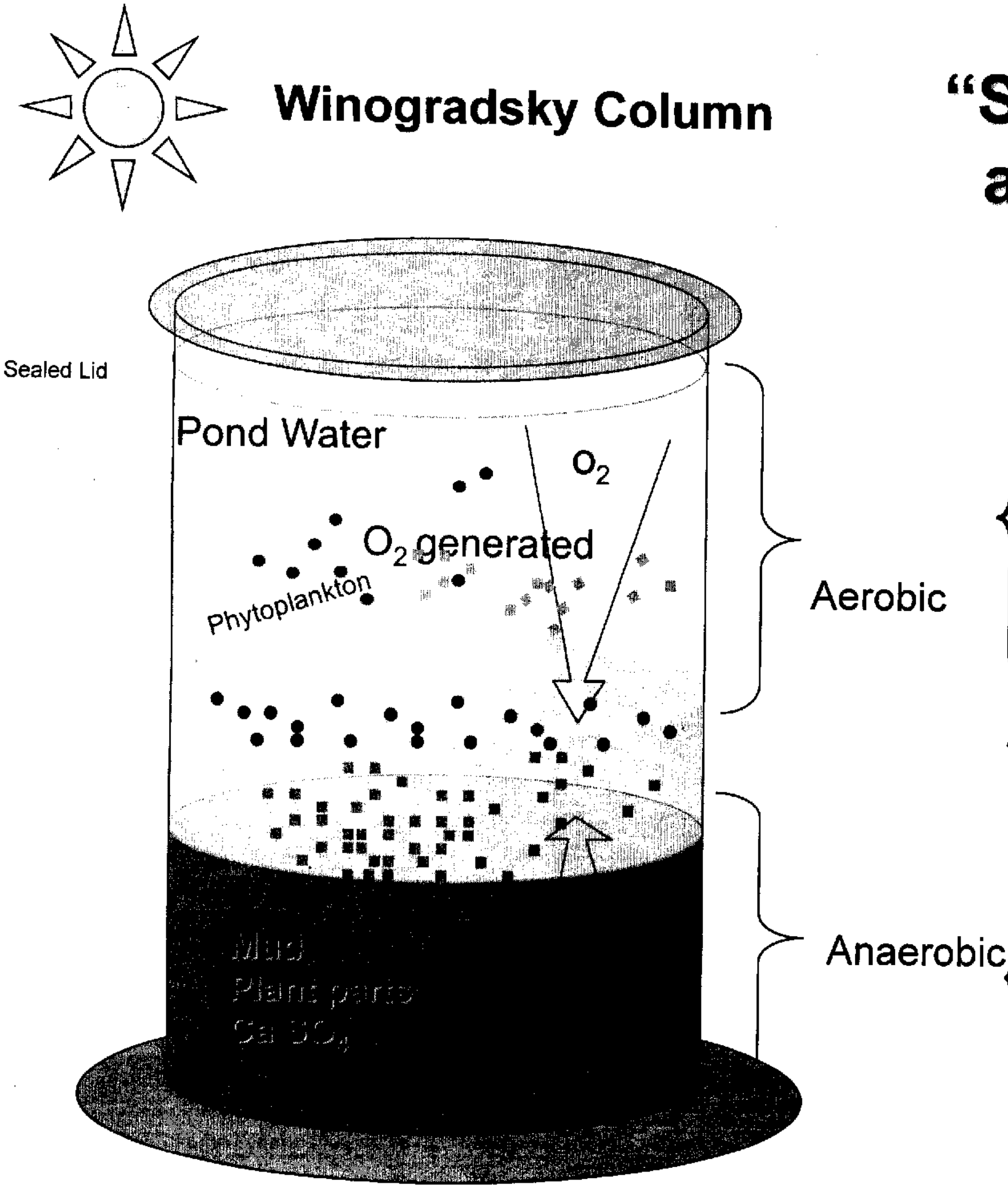
Calvin cycle produces glucose/sugars.
Note: Autotrophs carry out respiration too!

The Big Picture



5-2

"Self- Assembly" of a self- sustaining ecosystem



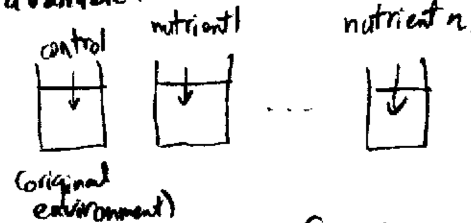
- Photosynthetic phytoplankton
- Aerobic heterotrophs

- Chemosynthetic bacteria
  Low O_2, H_2S

- Photosynthetic bacteria
  No O_2, H_2S, light
- Anaerobic respiration bacteria
  $SO_4^{2-} \rightarrow H_2S$
  Fermenters

Liebigs Law of the Minimum

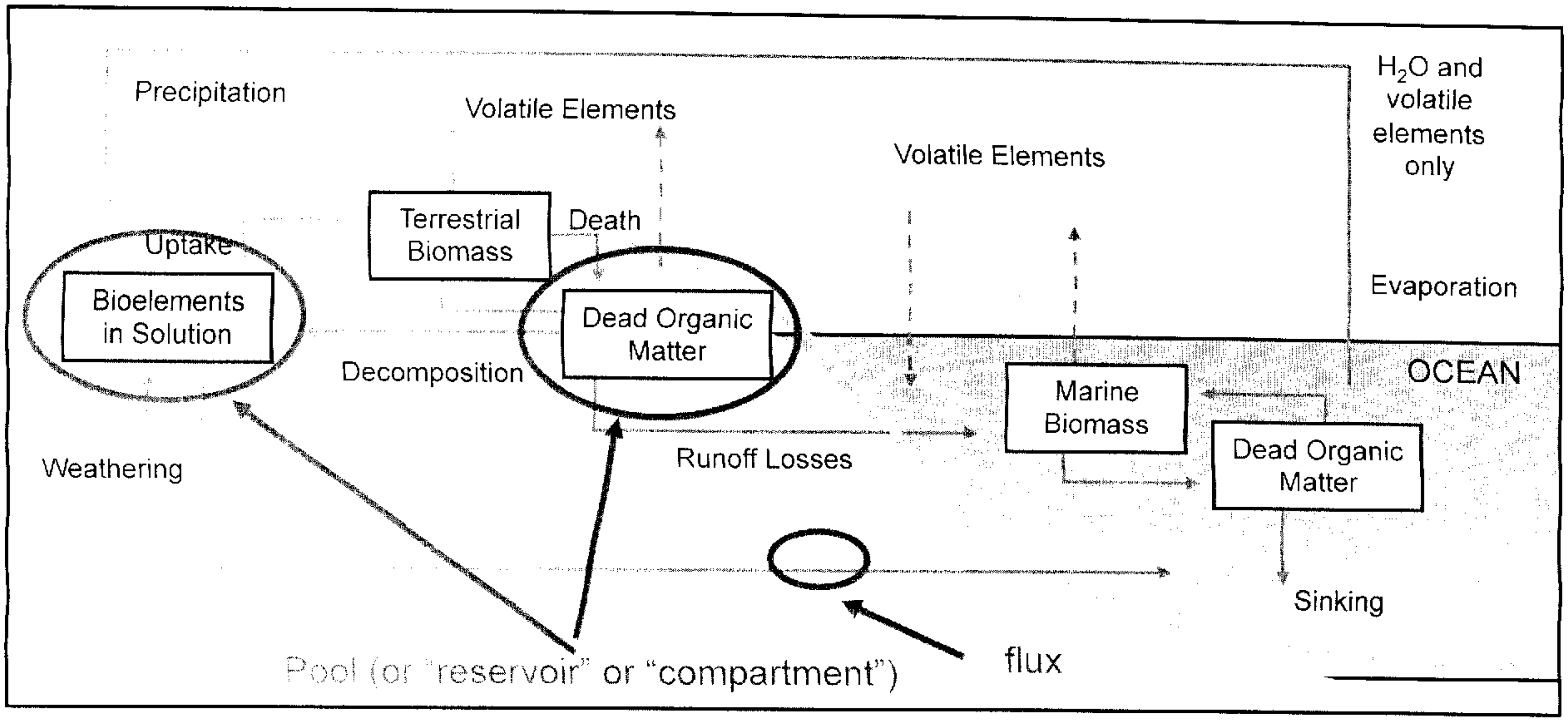
- The growth of plants or phytoplankton is limited by the element that is in least supply relative to what is required for growth.
- Phosphorus & nitrogen vs. limiting on land
- Calculate ratios. limiting = largest $\frac{\text{required}}{\text{available}}$.
- Experiment to find limiting nutrient: Which one causes more growth?
  Note: Once NH_4 is limiting, N_2 fixers will outcompete other phytoplankton.



Compare
- Optical density (cloudy => more phytoplankton)
- CO_2 consumption & O_2 production

→ In the open ocean the N:P ratio mirrored that of the phytoplankton
- organisms affect the chemical composition of their environment

Global Nutrient Cycling - Biogeochemical Cycles



Useful Conversion Factors

10^{12} g = 1 teragram = 1 Tg

~~10^9 g = 1 gigaton = 1 gt~~

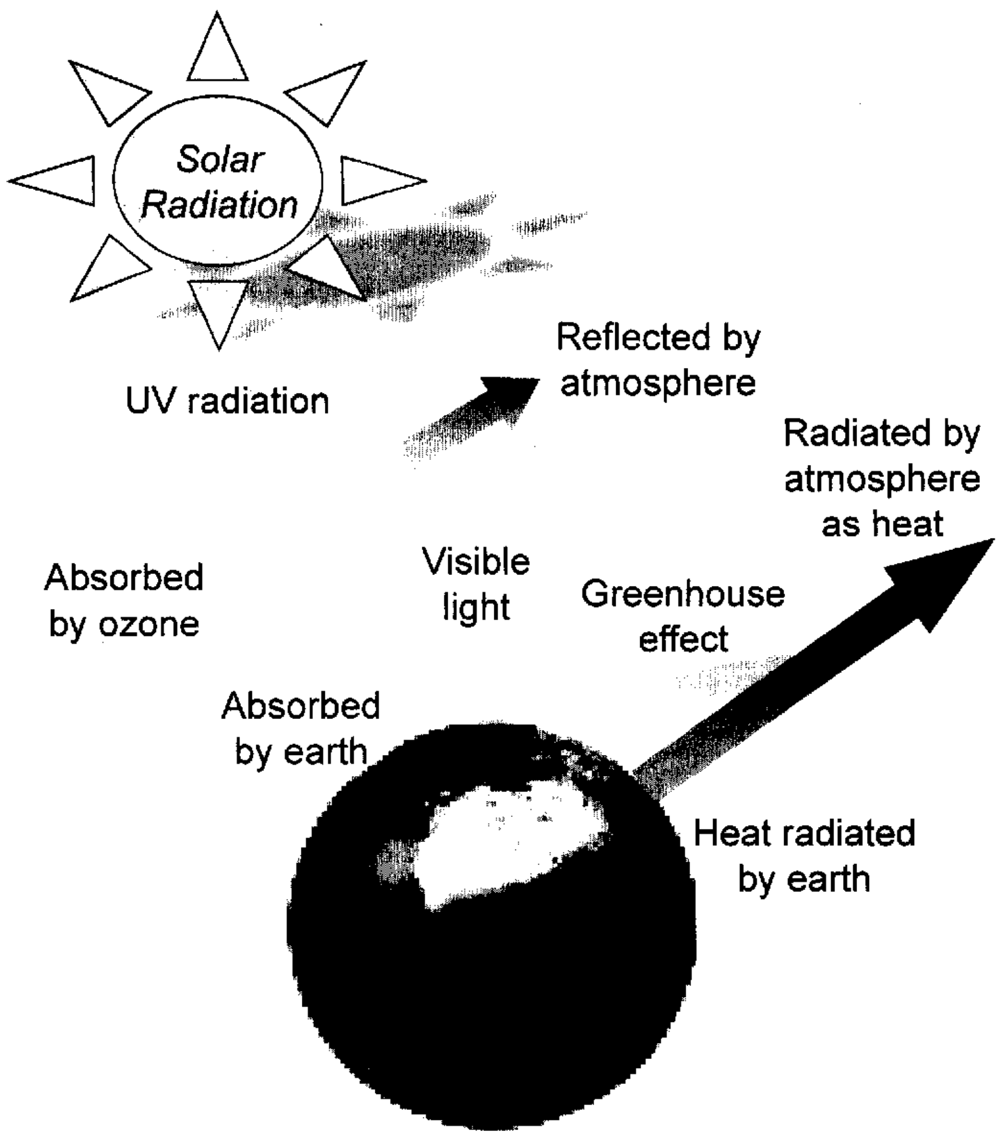
10^6 g = 1 metric ton = 1 tonne

Mean Residence Time (MRT)

= pool size / mean flux in or out of pool

Fractional Turnover = 1 / MRT

= fraction that is removed and replaced per unit time



Energy In = Energy Out

Solar Energy Budget

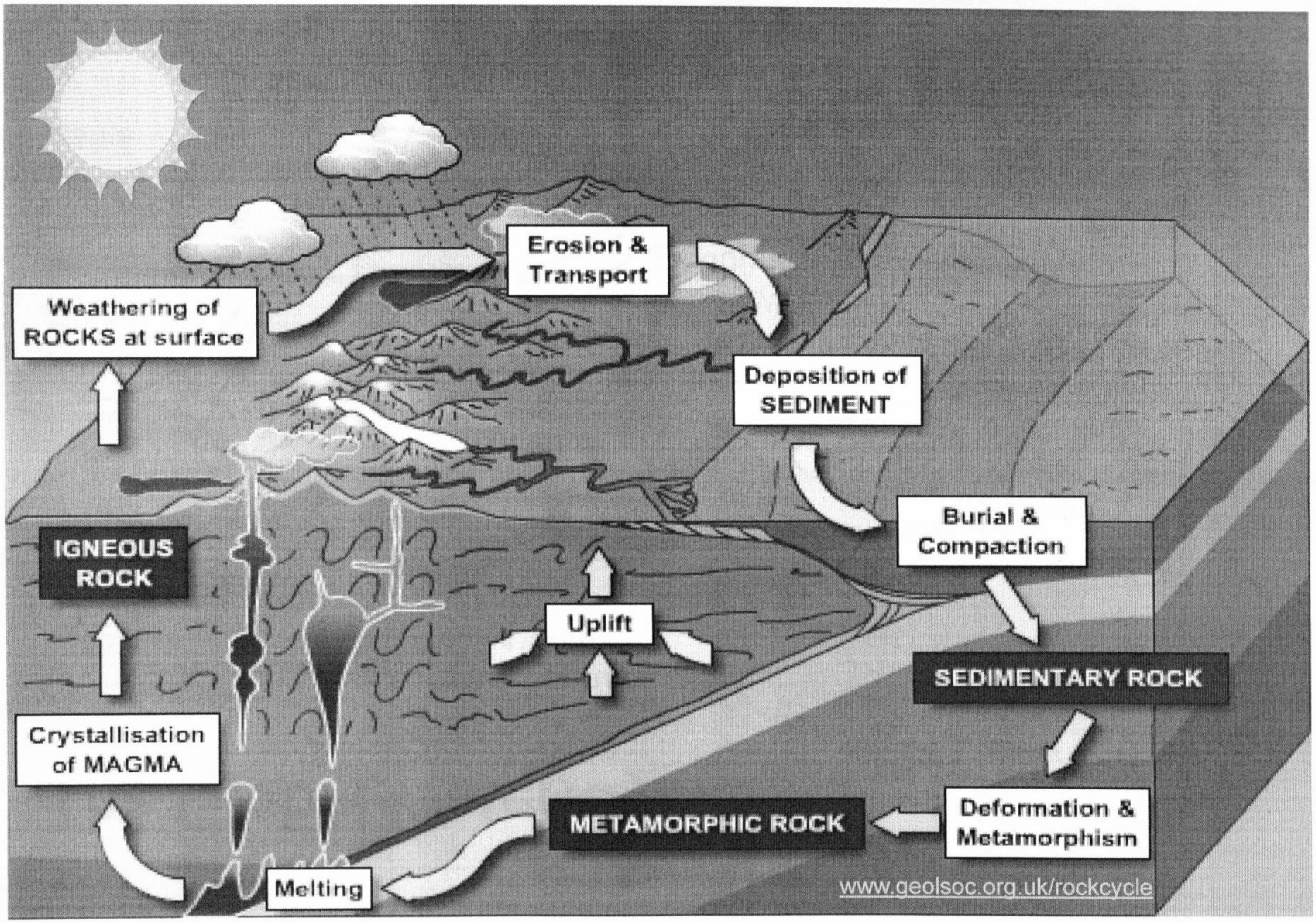
Total From Sun	100%
(1.3×10^{21} kcal per year)	
Reflected	30%
Absorbed (heat)	47%
Used in Evaporation	23%
Used in Winds & Currents	0.2%
Used in Photosynthesis	0.002%

Used to Drive the Cycles

Source of energy to *most* ecosystems on Earth is Solar Radiation

The Geologic Cycle (slow!)
Powered by Solar & Geothermal Energy

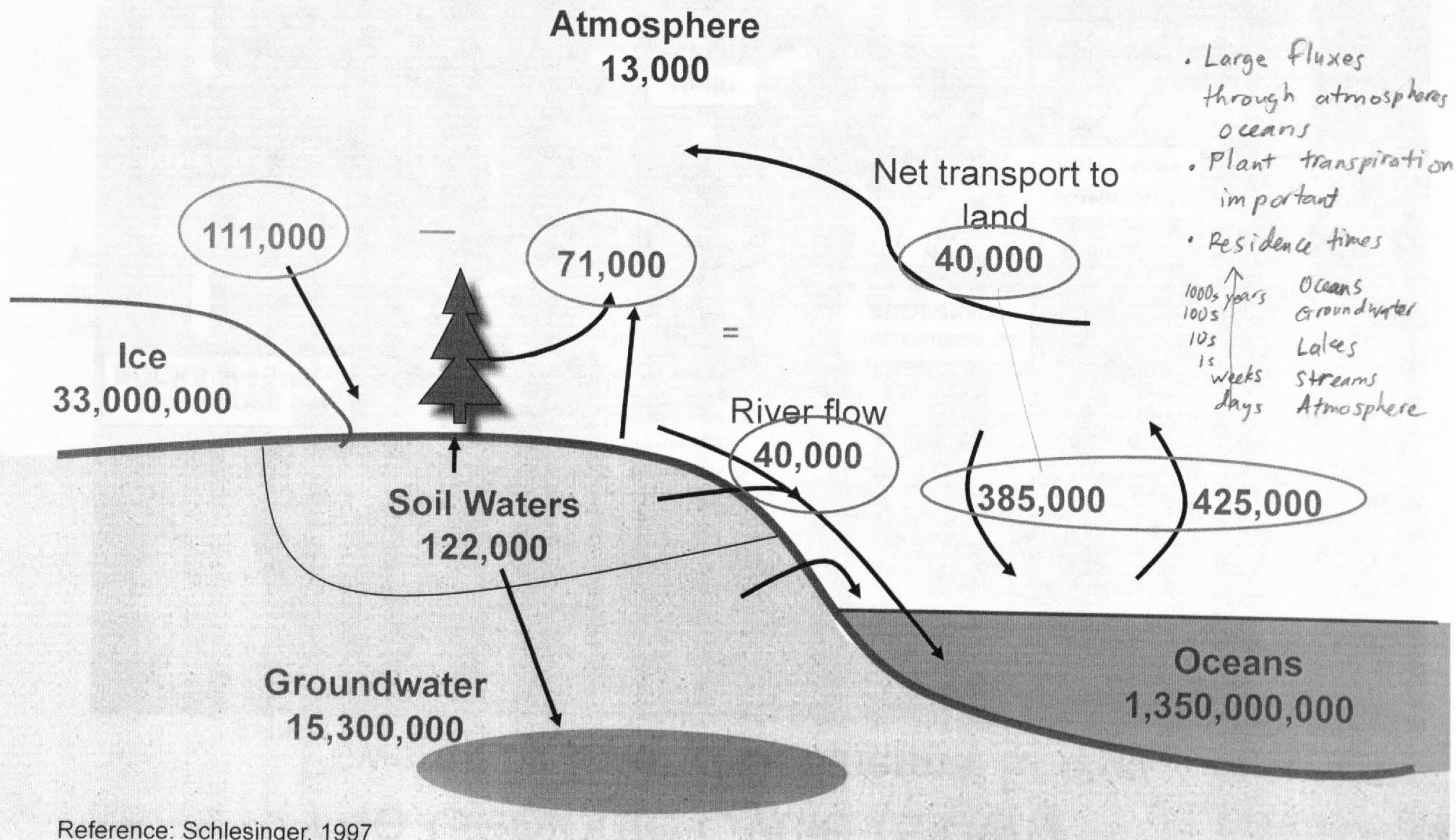
Rock weathering critical to availibility of elements without gaseous form (Ca, K, Fe, P, ..)



The Global Water Cycle

Pools (km^3)

Fluxes (km^3/yr)

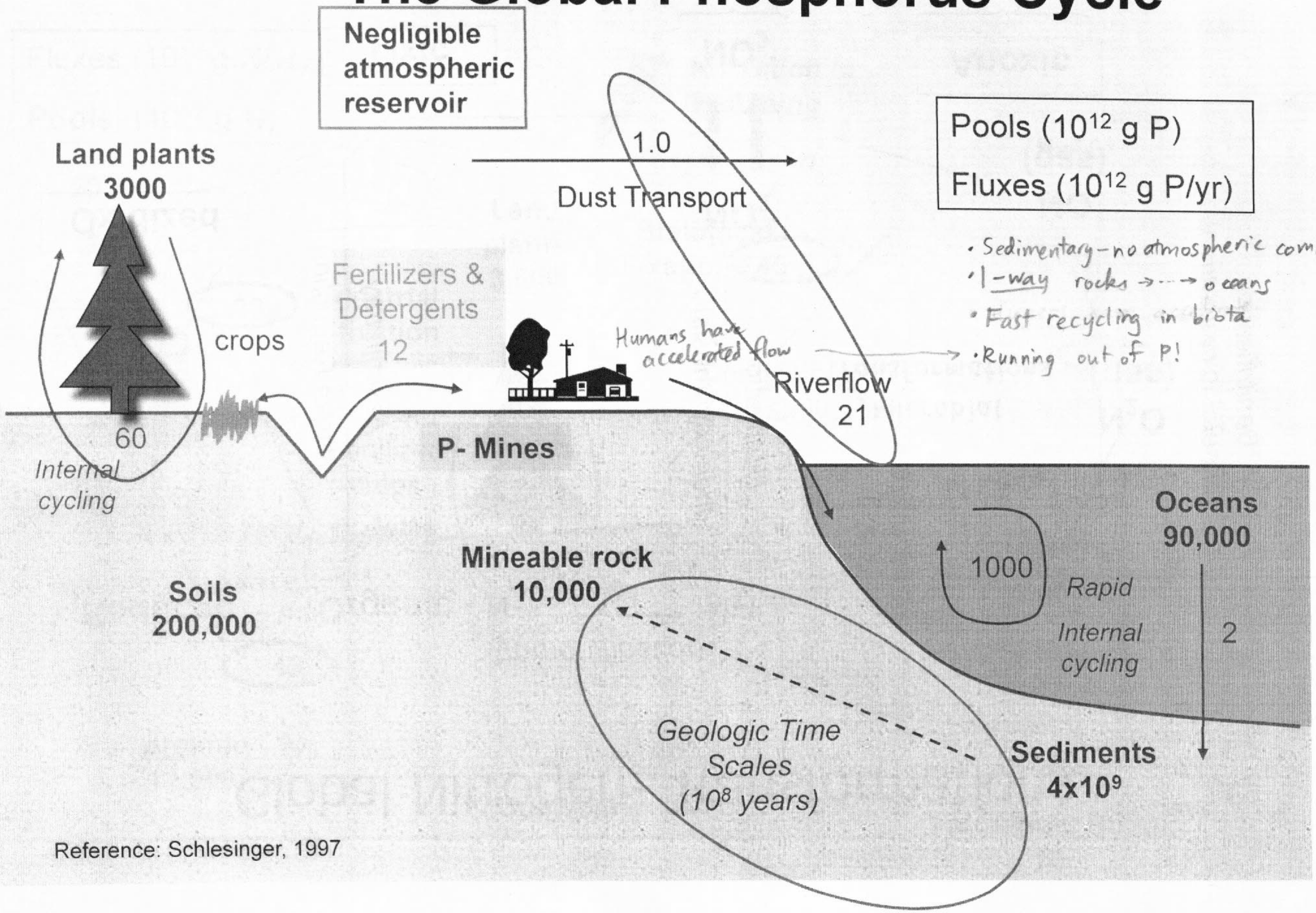


- Large fluxes through atmospheres & oceans
- Plant transpiration important
- Residence times

1000s years	Oceans
100s	Groundwater
10s	Lakes
1s	
weeks	Streams
days	Atmosphere

Reference: Schlesinger, 1997

The Global Phosphorus Cycle



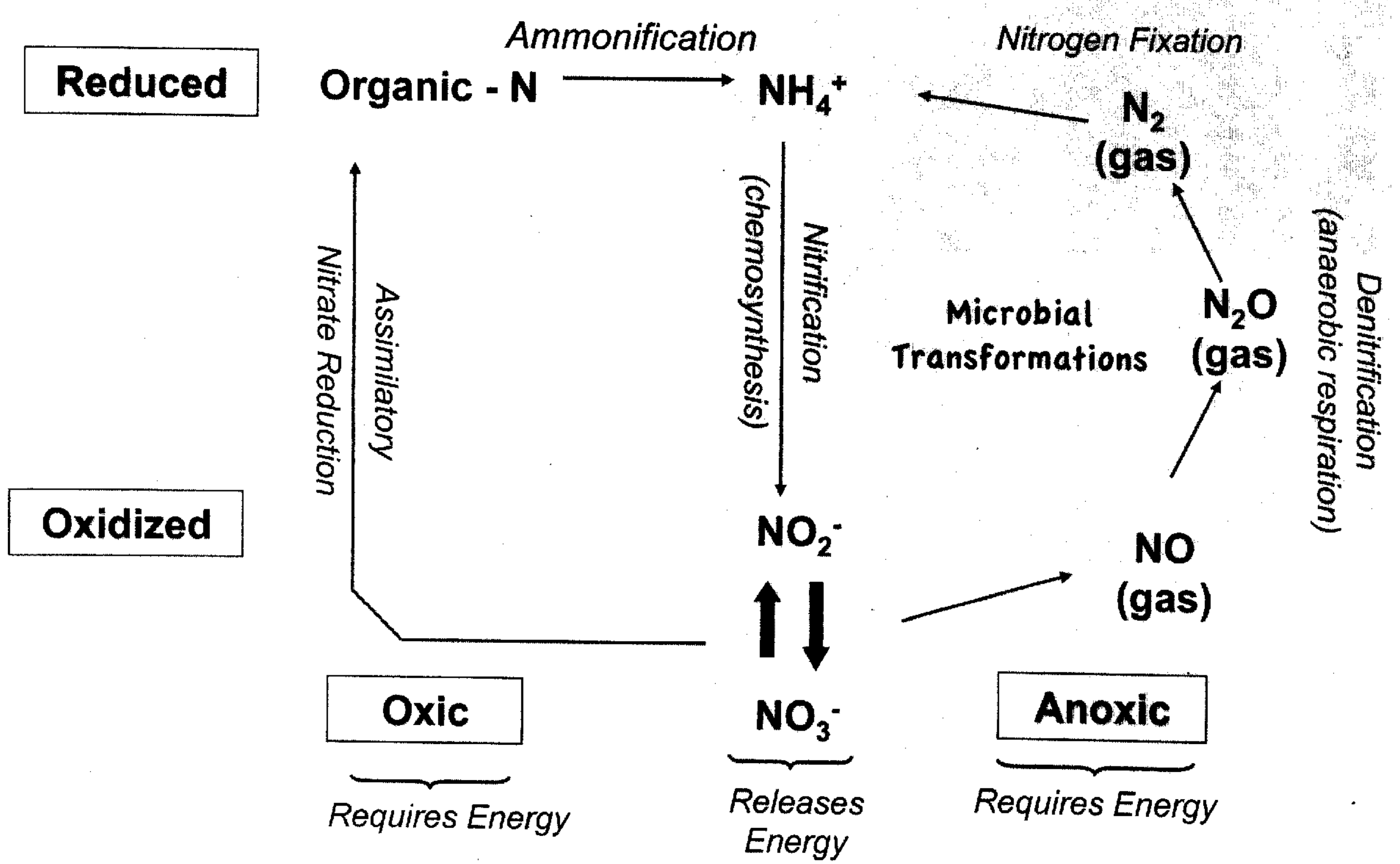
- Sedimentary – no atmospheric component
- 1-way rocks → ... → oceans
- Fast recycling in biota
- Running out of P!

Reference: Schlesinger, 1997

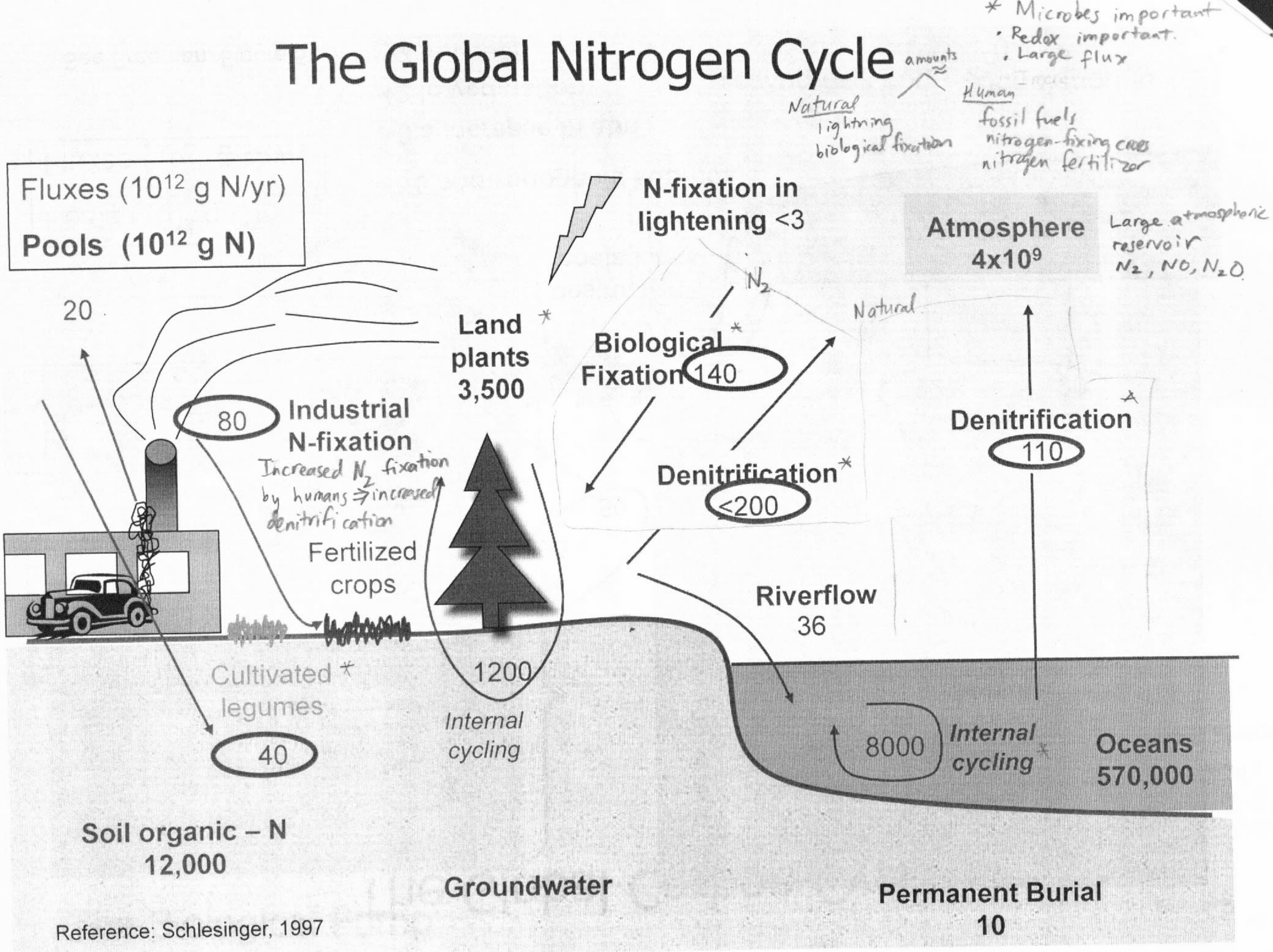
Global Nitrogen- Transformations

Denitrification

NAD^+ $NADH$ e^- NO_3^- N_2



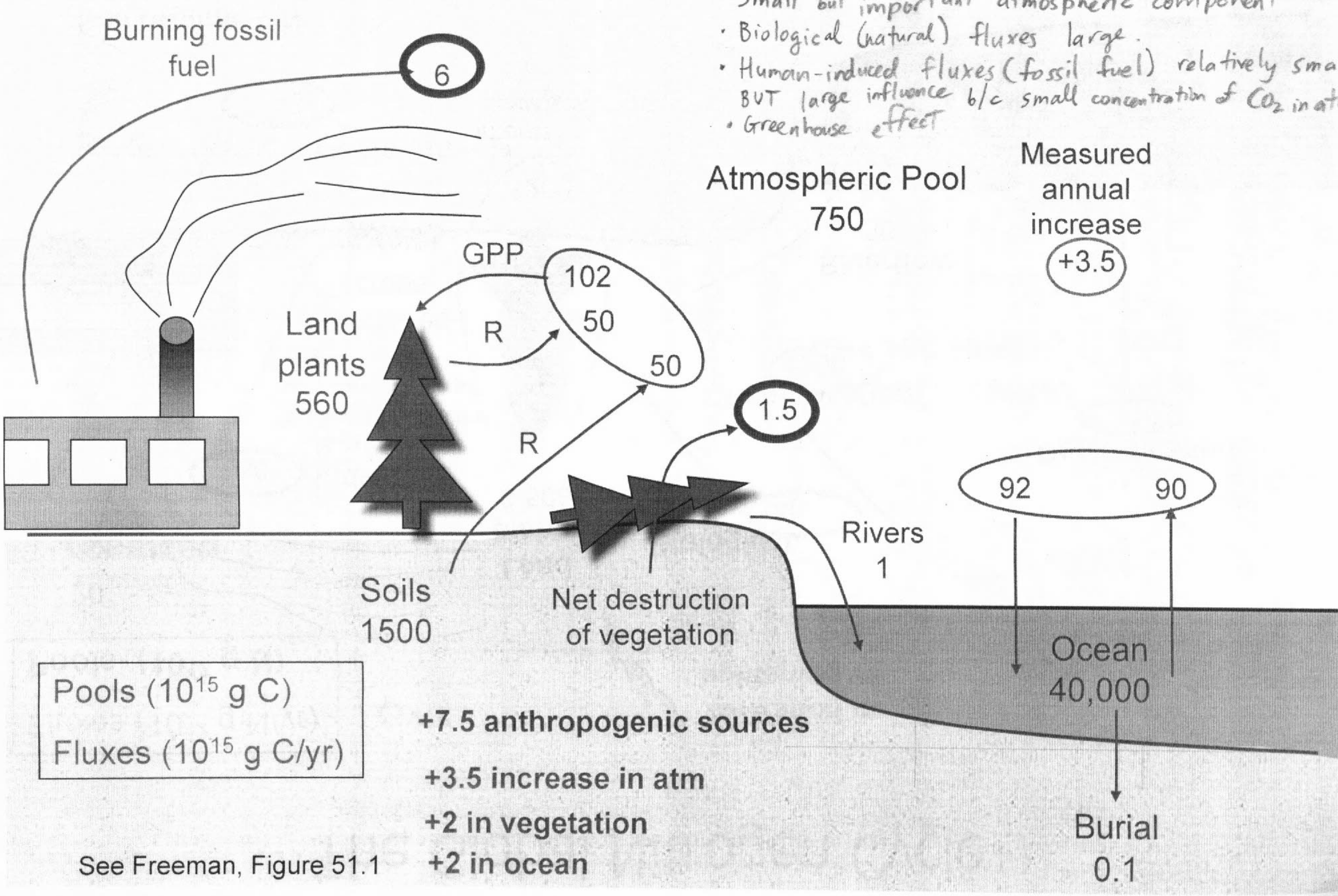
The Global Nitrogen Cycle



Reference: Schlesinger, 1997

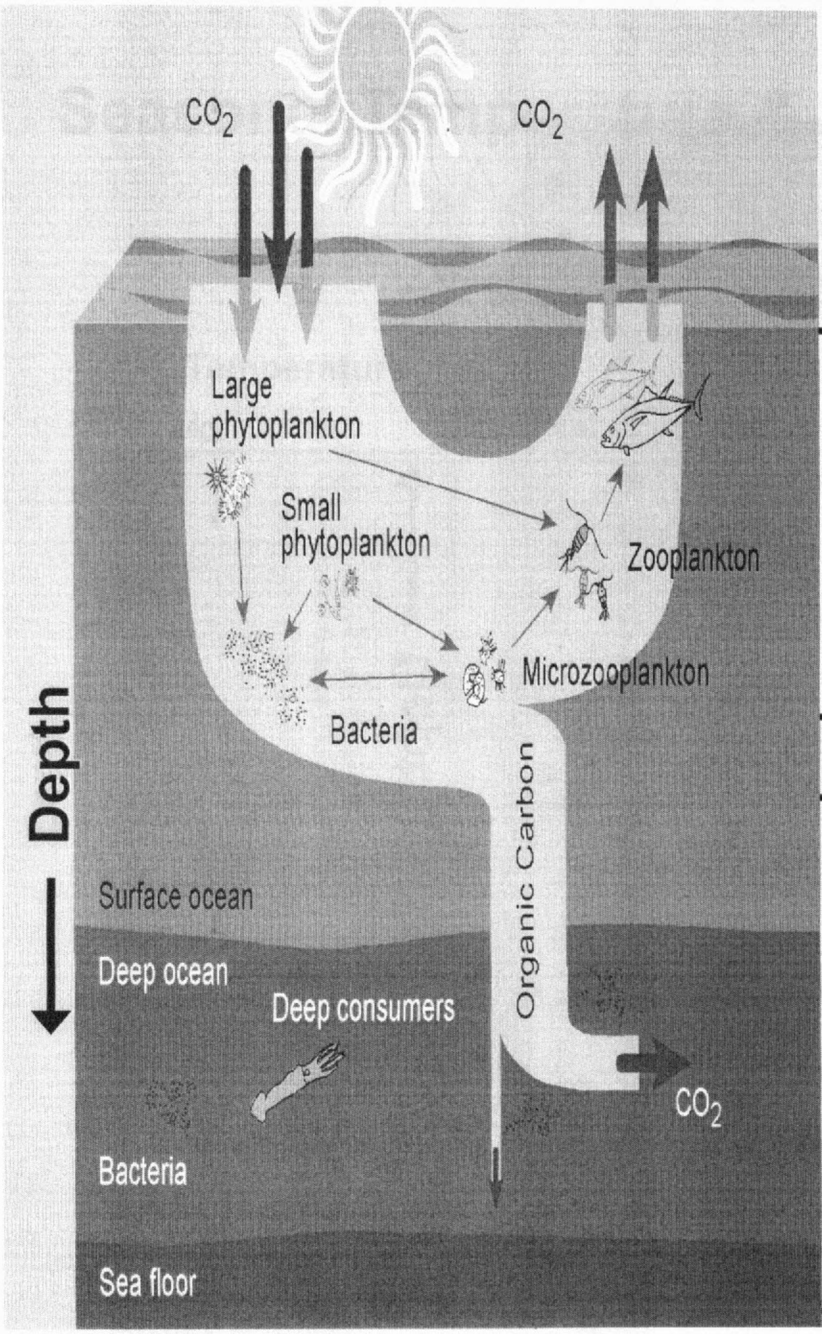
The Global Carbon Cycle

- Small but important atmospheric component
- Biological (natural) fluxes large.
- Human-induced fluxes (fossil fuel) relatively small BUT large influence b/c small concentration of CO_2 in atmosphere
- Greenhouse effect



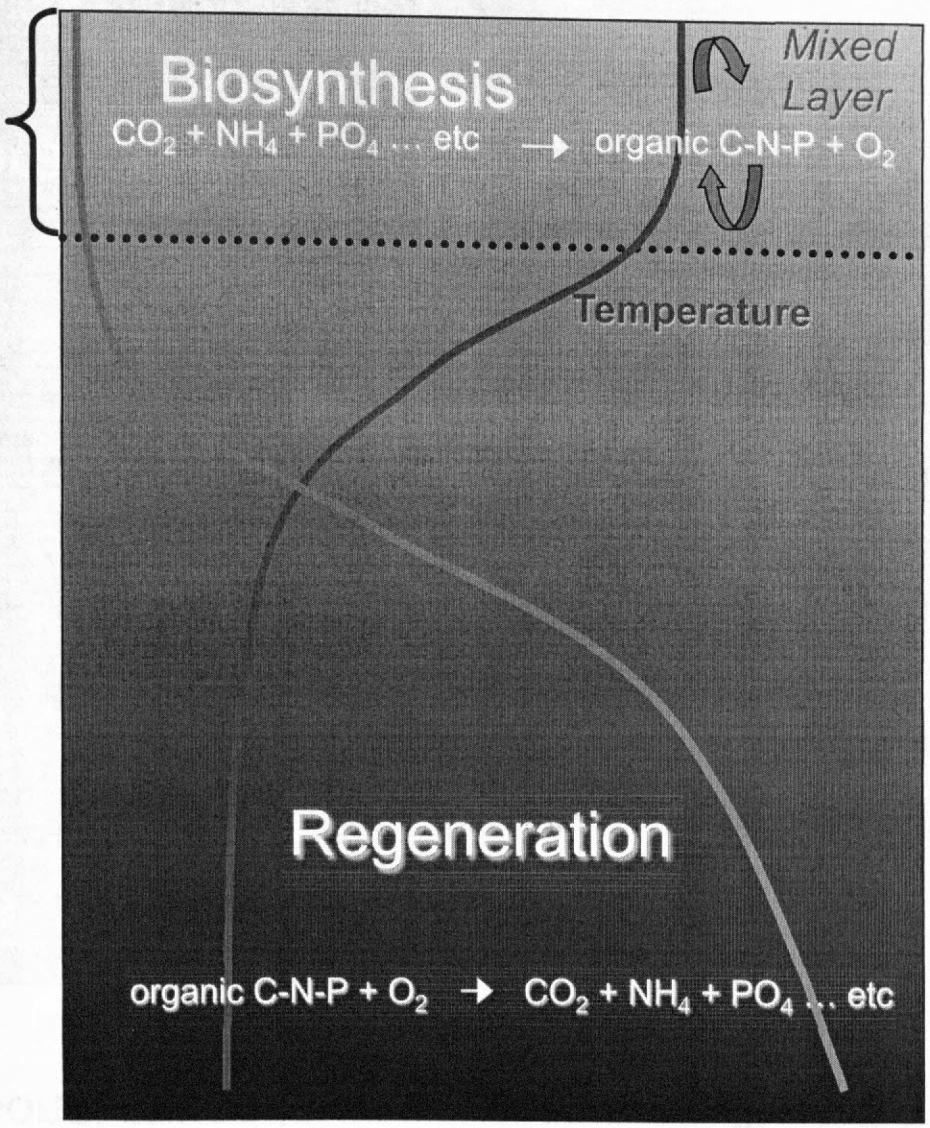
See Freeman, Figure 51.1

(6-2)



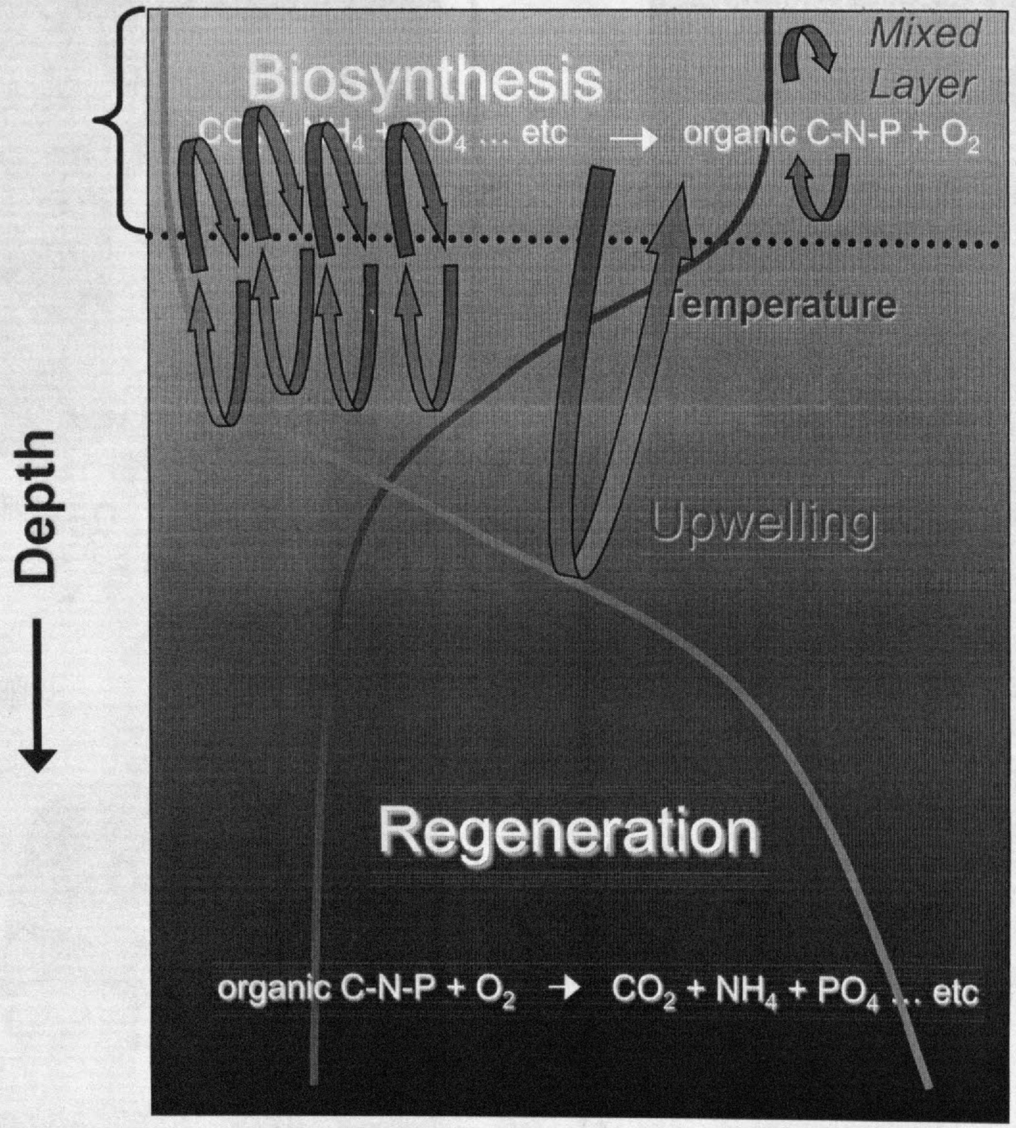
The Biological Pump

Biosynthesis and Regeneration in the oceans



Nutrients

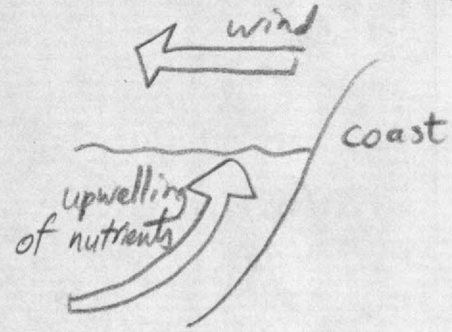
1) Periodic mixing below the seasonal mixed layer causing upwelling



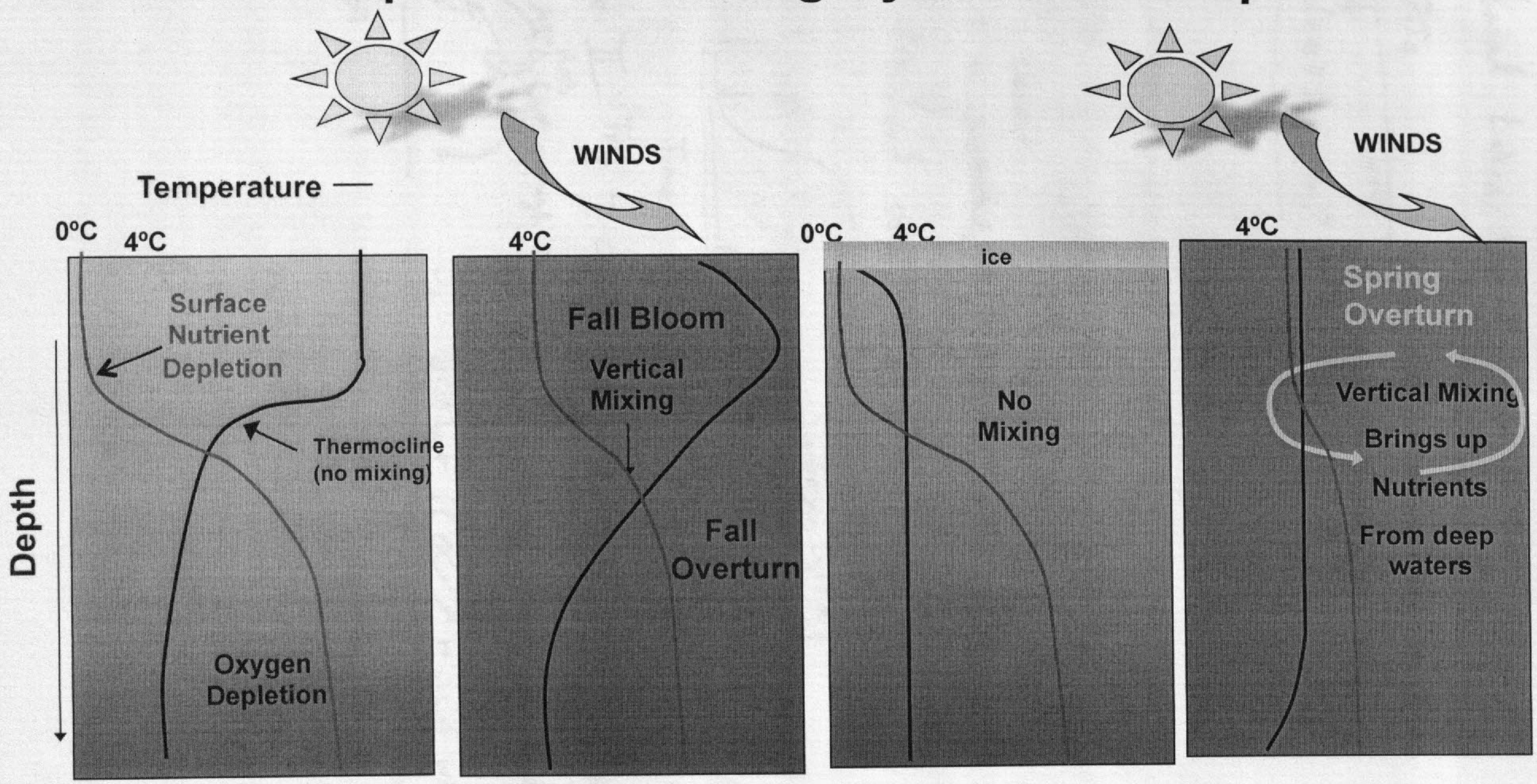
cold, nutrient-rich.

Upwelling

- Marine Primary Production higher in zones of upwelling
warm
- Nutrients sink to bottom
⇒ upwelling /mixing brings them back up.
- Thermocline - gradient of temperature in water.



Seasonal Temperature & Mixing Cycles in a Temperate Lake



SUMMER

Warm suface waters, strong stratification ***(Thermocline, No deep mixing, Nutrient Depletion in Surface Waters)***

FALL

Surface Layers Cool and Sink ***(Mixing, Nutrient-Rich Waters Rise)***

WINTER

Low Temperatures

(Low Mixing, Low Solar Radiation)

SPRING

Spring Overturn, Spring Bloom ***(Winds, Deep Mixing, Nutrients Mix to Surface, Solar Radiation)***

Thermocline Develops

Ecological Experiments

- Experiments on whole ecosystems useful

- Experimental Lakes Area, Ontario

$+PO_4$

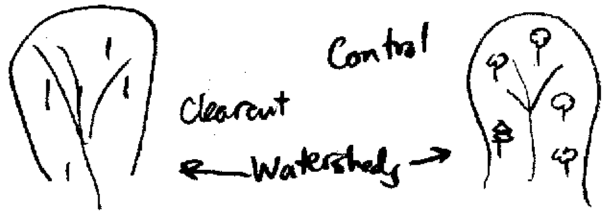
Lake

relieves P limitation → makes N limiting

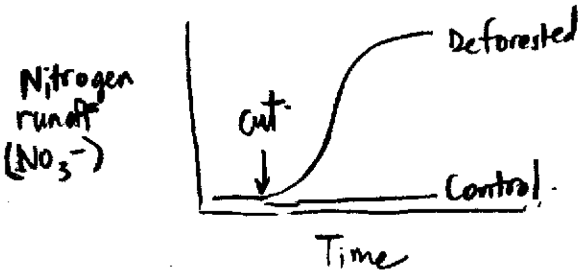
↓

stimulates N_2 fixing algae.

- Hubbard Brook Experimental Forest, NH



Measure dissolved substances in streams

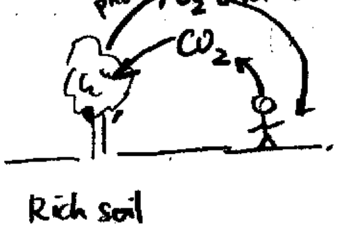


(show: lots of nitrogen cycled in plants)

- Biosphere II: Try to create livable environment in greenhouse

photosynthesis O_2 (not enough to sustain humans — heterotrophic bacteria in rich soil take in O_2)

└ throw out of balance



O_2 ↘ but CO_2 ↗ — react w/ cement infrastructure

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

7 Productivity

roductivity - organisms assimilating carbon

Primary Producers - autotrophs (photosynthesis)

econdary Producers - heterotrophs

Production - per unit surface area

Productivity - total for whole ecosystem

Primary Production

Gross primary production (GPP)
Total CO_2 reduced to organic carbon (by plants) per unit time

Autotrophic respiration (R_A)
Total organic carbon respired (oxidized to CO_2)

Net primary production
$NPP = GPP - R_A$
organic carbon produced by plants not consumed by their own respiration

Heterotrophic respiration (R_H)
Organic carbon respired

Net community production
$NCP = NPP - R_H$
organic carbon produced through photosynthesis (& built up) not lost through respiration

NCP = 0 for community in steady state, > 0 for nonmature ecosystem.

For steady state:
Mean residence time

$$MRT = \frac{\text{biomass/area}}{\text{flux (GPP)}} \quad [\text{time}]$$

Fractional turnover

$$k = \frac{1}{MRT} \quad \left[\frac{1}{\text{time}}\right]$$

Energy Flow

Trophic level n.

P_{n-1} net productivity at level n-1

I_n amount ingested at trophic level n

A_n amount assimilated, available for metabolism

R_n respiration
- energy lost as heat
- unavailable to others.
- most of energy!

P_n Productivity at trophic level n

D_n: amount of P_{n-1} not consumed by trophic level n (die before eaten)

F_n: fecal matter

Exploitation efficiency
$$EE = \frac{I_n}{P_{n-1}} = \frac{\text{ingest}}{\text{available}}$$

Phyto → zooplankton High
Grass → animals
Tree → insect Low

Assimilation efficiency
$$AE = \frac{A_n}{I_n} = \frac{\text{assimilate}}{\text{ingest}}$$

The more similar to food, the higher
Carnivores
herbivores

Production efficiency (not lost to respiration)
$$PE = \frac{P_n}{A_n} = \frac{\text{produced}}{\text{assimilated}}$$

Cold-blooded
warm-blooded

Dead organic matter

Particulate organic carbon (POC) → Detritus food web

Dissolved organic carbon (DOC) → Microbial food web

Refractory Carbon

buildup of carbon in environment (NCP) when not steady state

Ecological efficiency
$$= EE \cdot AE \cdot PE = \frac{P_n}{P_{n-1}}$$
- Fraction of energy going to next trophic level

usually 10-20%

Ecological Efficiencies

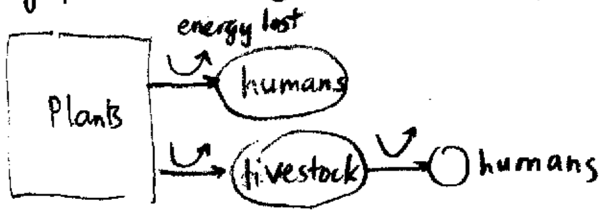
$$E_n = NPP \cdot Eff_a^{\,n-1} \xrightarrow{\text{solve}} n = 1 + \frac{\log E_n - \log NPP}{\log Eff_a}$$

E_n: energy available at n^{th} trophic level

Eff_a: mean transfer efficiency.

(Primary producers: $n = 0$)

Eating plants more efficient than eating meat → need to grow less food

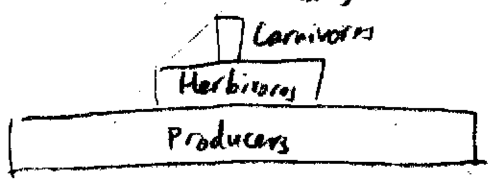


Pyramids of biomass & productivity

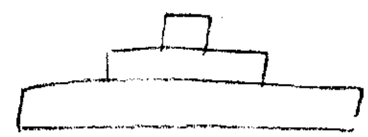
Biomass ($\frac{g}{m^2}$)

Carbon (energy) flow ($\frac{g}{m^2 \cdot day}$)

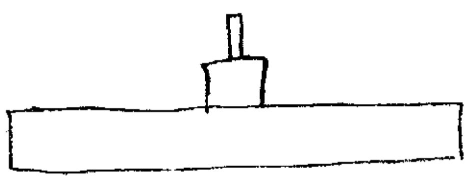
Grassland



← biomass in plants accessible to herbivores

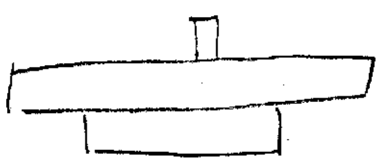


Forest

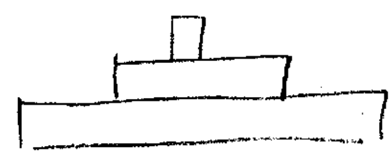


← biomass in wood mostly unavailable to herbivores

Open Ocean



← inverted pyramid of biomass: Phytoplankton grow & reproduce quickly so can support a larger biomass of zooplankton. (eaten quickly)



must be pyramidal for all ecosystems