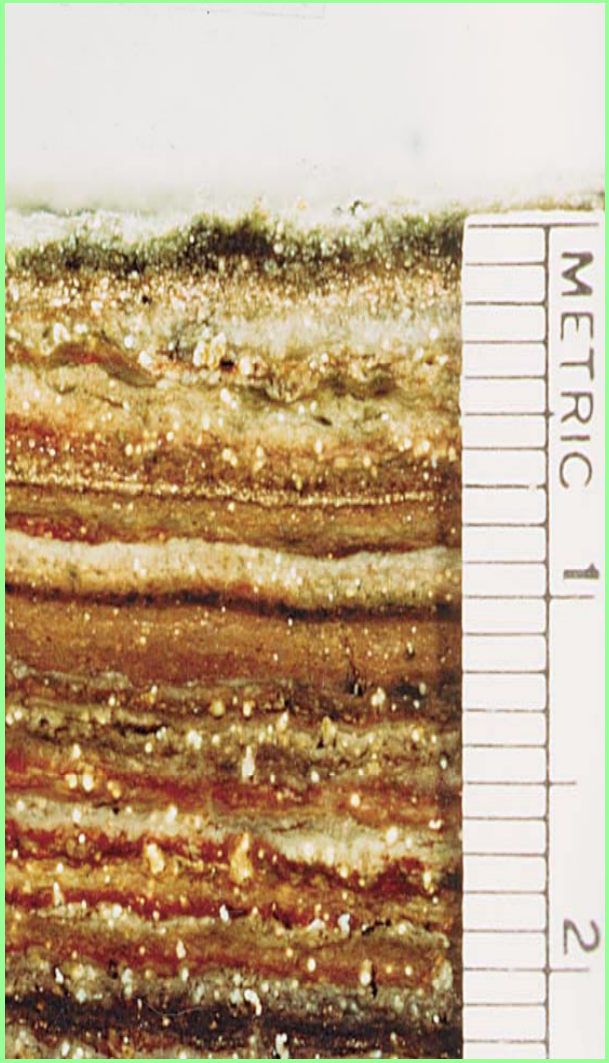
Microbes and Mineral Cycling

Biogeochemical cycles on a
global scale

Photosynthesis Is the Source of Atmospheric O_2

- Cyanobacteria, which evolved the ability to split water into hydrogen ions and O_2, created atmospheric O_2.
- Accumulation of free O_2 in the atmosphere made possible the evolution of aerobic metabolism.

Extant Microbial Mat Communities



Rust the Crust

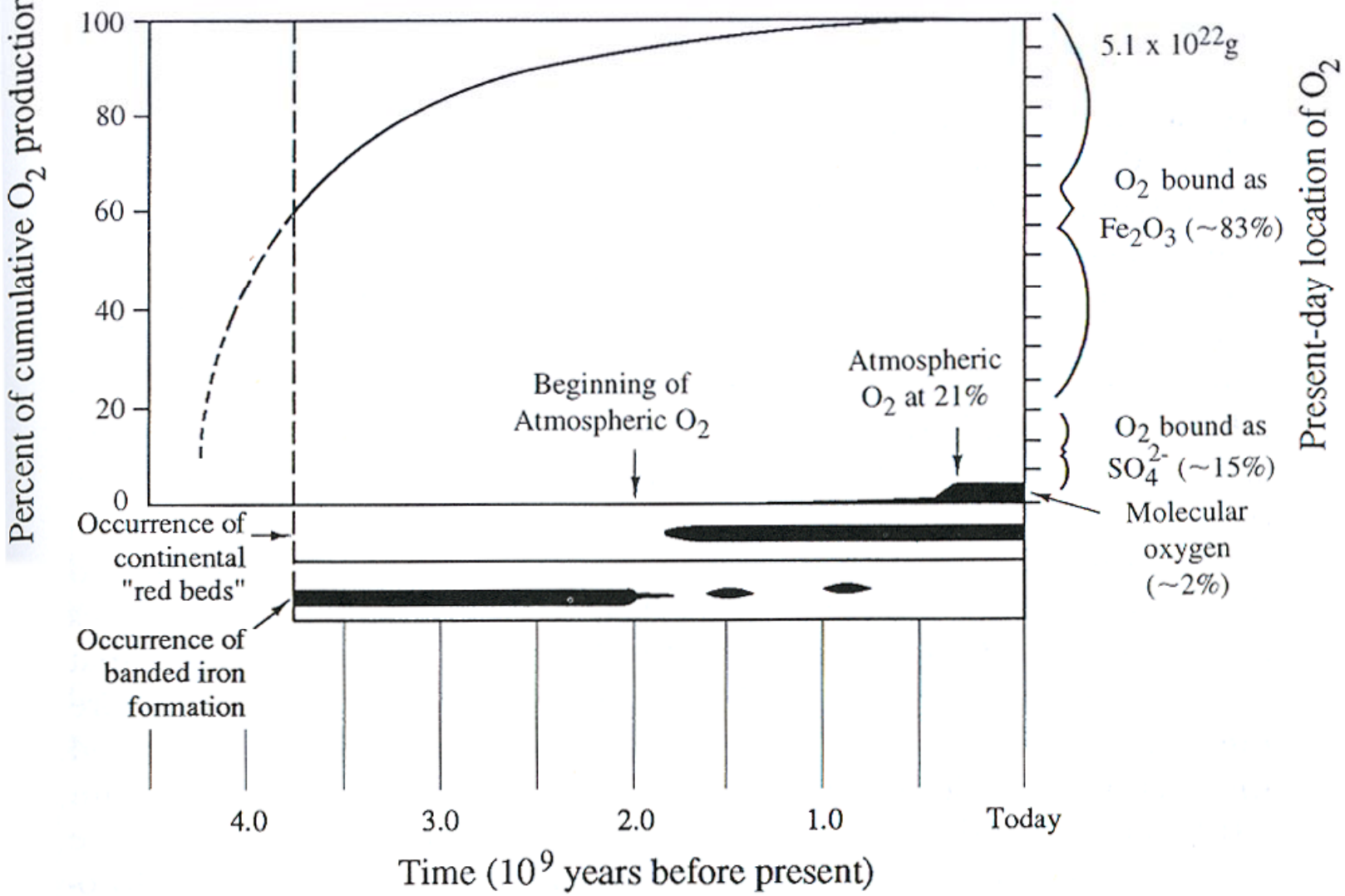
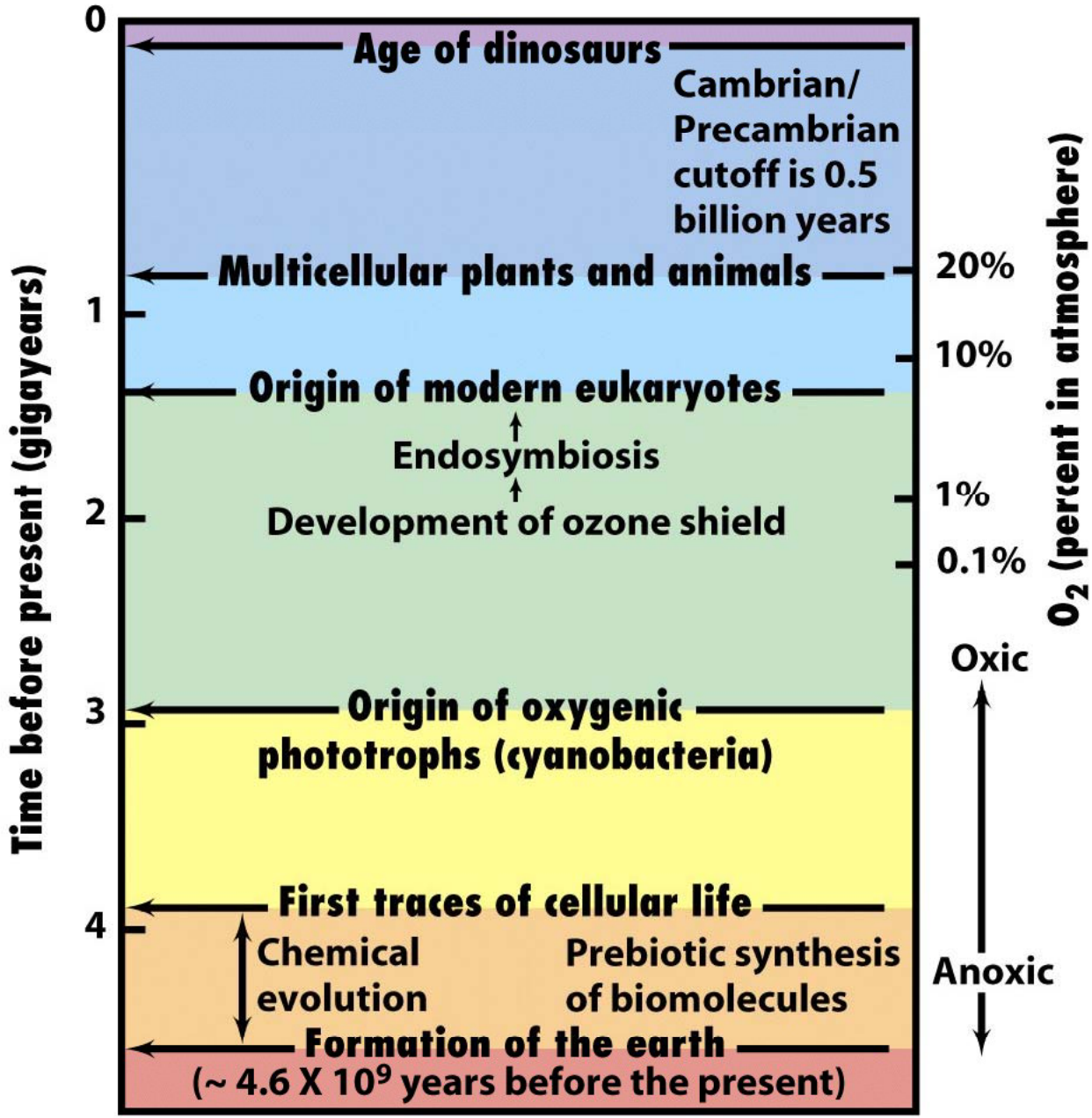
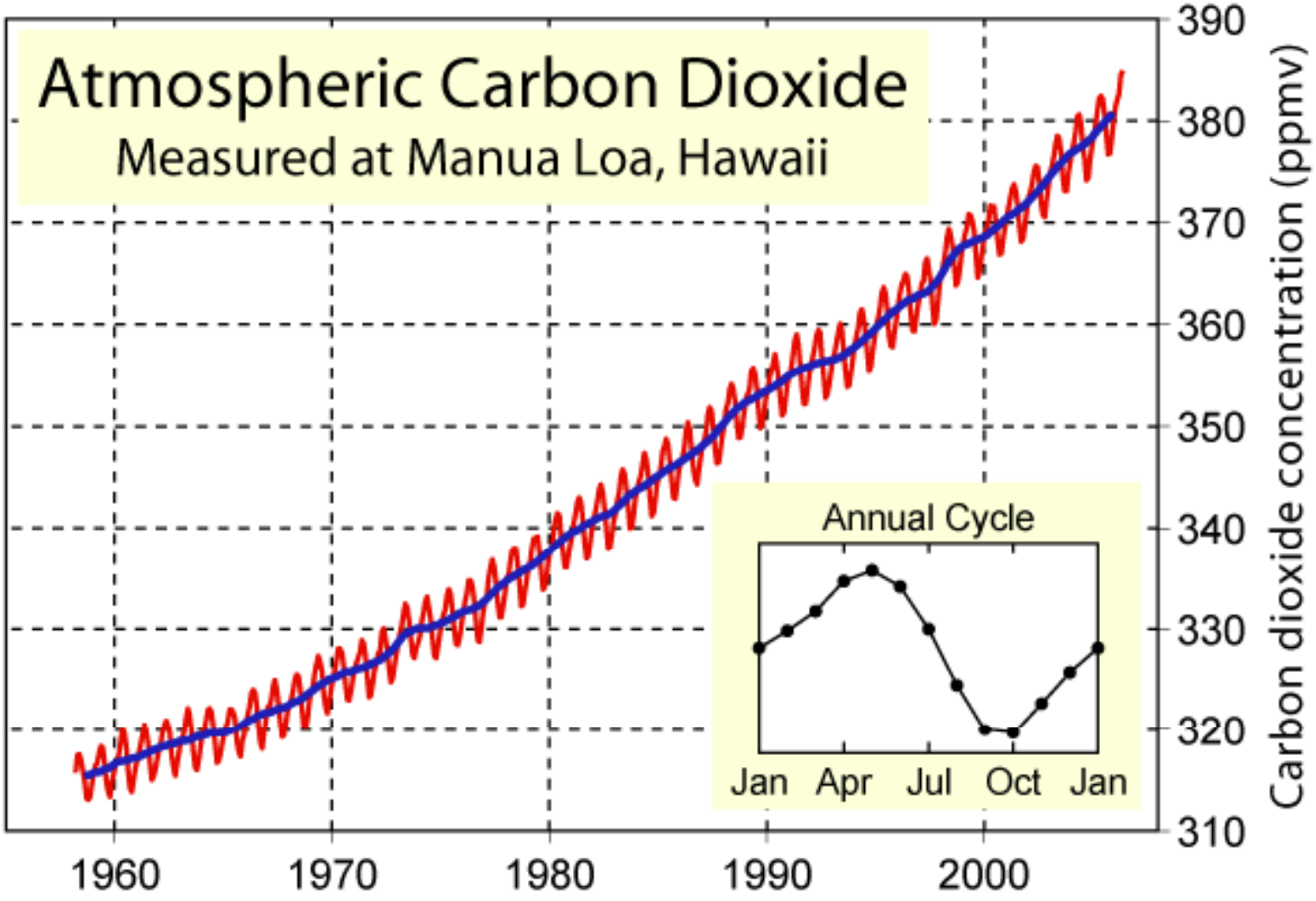


Figure 2.7 Cumulative history of O_2 released by photosynthesis through geologic time. Of more than 5.1×10^{22} g of O_2 released, about 98% is contained in seawater and sedimentary rocks, beginning with the occurrence of Banded Iron Formations at least 3.5 billion years ago (bya). Although O_2 was released to the atmosphere beginning about 2.0 bya, it was consumed in terrestrial weathering processes to form Red Beds, so that the accumulation of O_2 to present levels in the atmosphere was delayed to 400 mya. Modified from Schidlowski (1980).

Banded iron formations are evidence of oxygenic photosynthesis


Time before present (gigayears)
0
1
2
3
4
Age of dinosaurs
Cambrian/
Precambrian
cutoff is 0.5
billion years
Multicellular plants and animals
Origin of modern eukaryotes
Endosymbiosis
Development of ozone shield
Origin of oxygenic
phototrophs (cyanobacteria)
First traces of cellular life
Chemical
evolution
Prebiotic synthesis
of biomolecules
Formation of the earth
(~ 4.6 X 10^9 years before the present)
20%
10%
1%
0.1%
O2 (percent in atmosphere)
Oxic
Anoxic


Atmospheric Carbon Dioxide
Measured at Manua Loa, Hawaii
Annual Cycle
Jan
Apr
Jul
Oct
Jan
1960
1970
1980
1990
2000
310
320
330
340
350
360
370
380
390
Carbon dioxide concentration (ppmv)

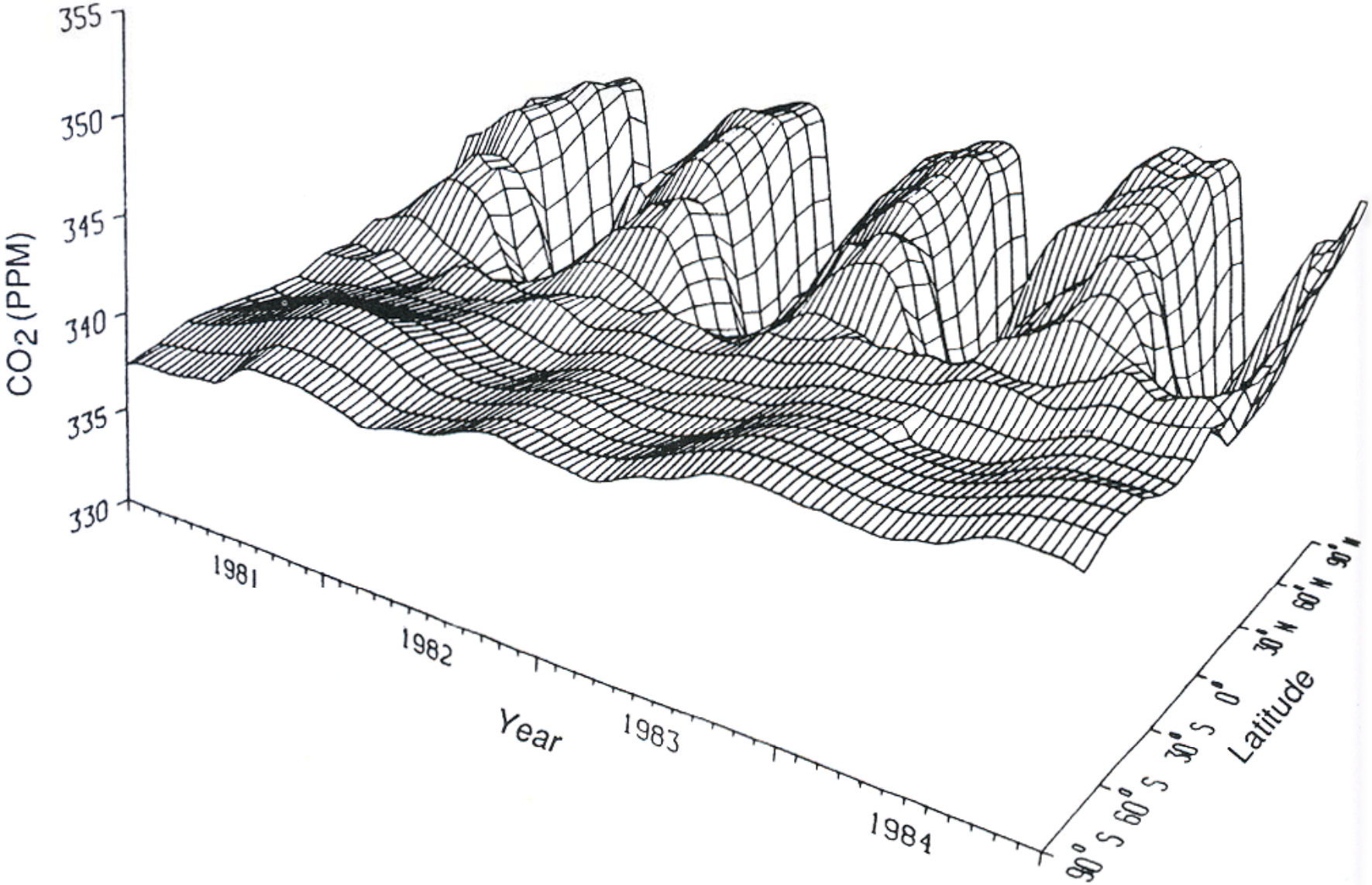
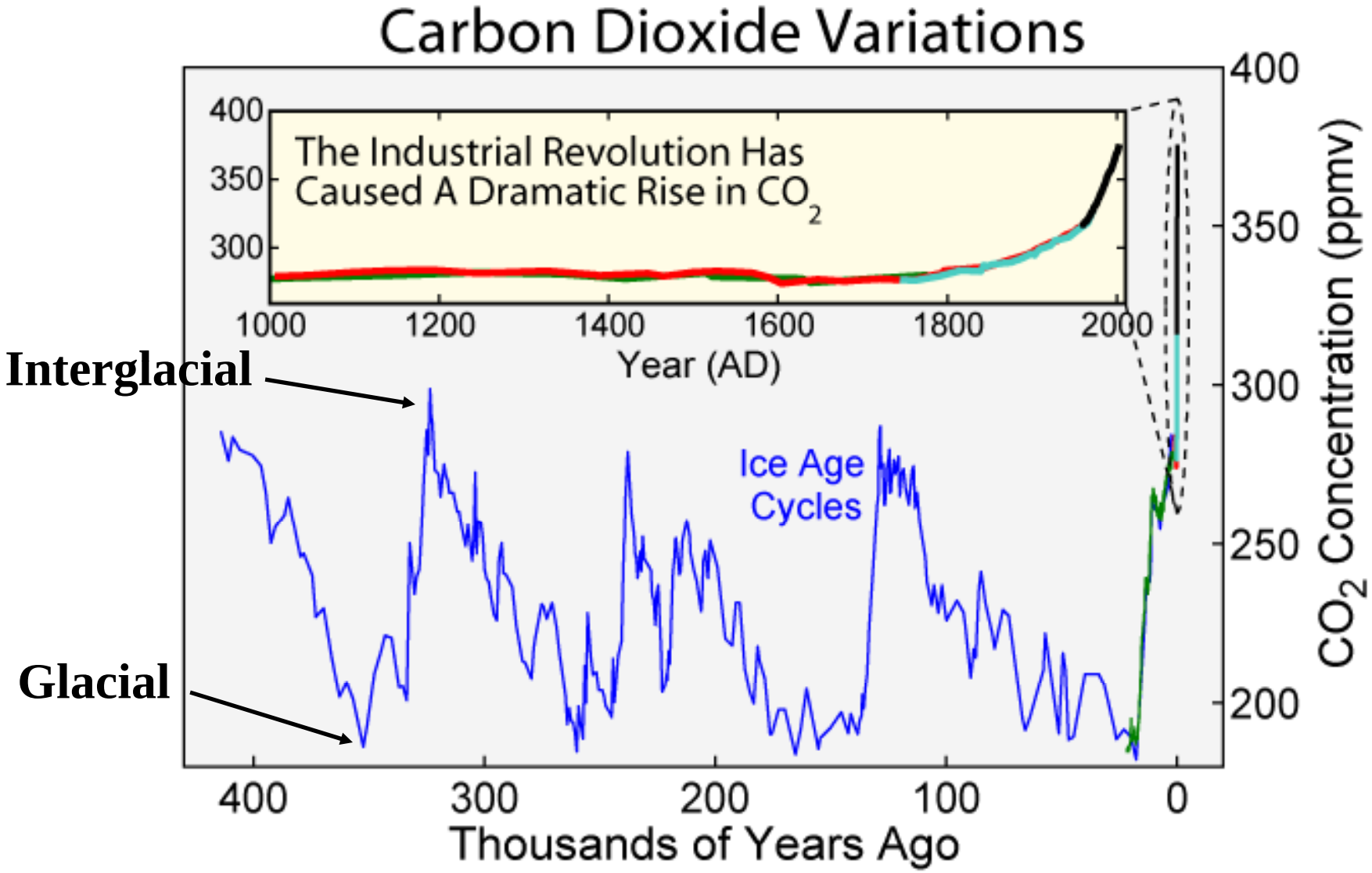
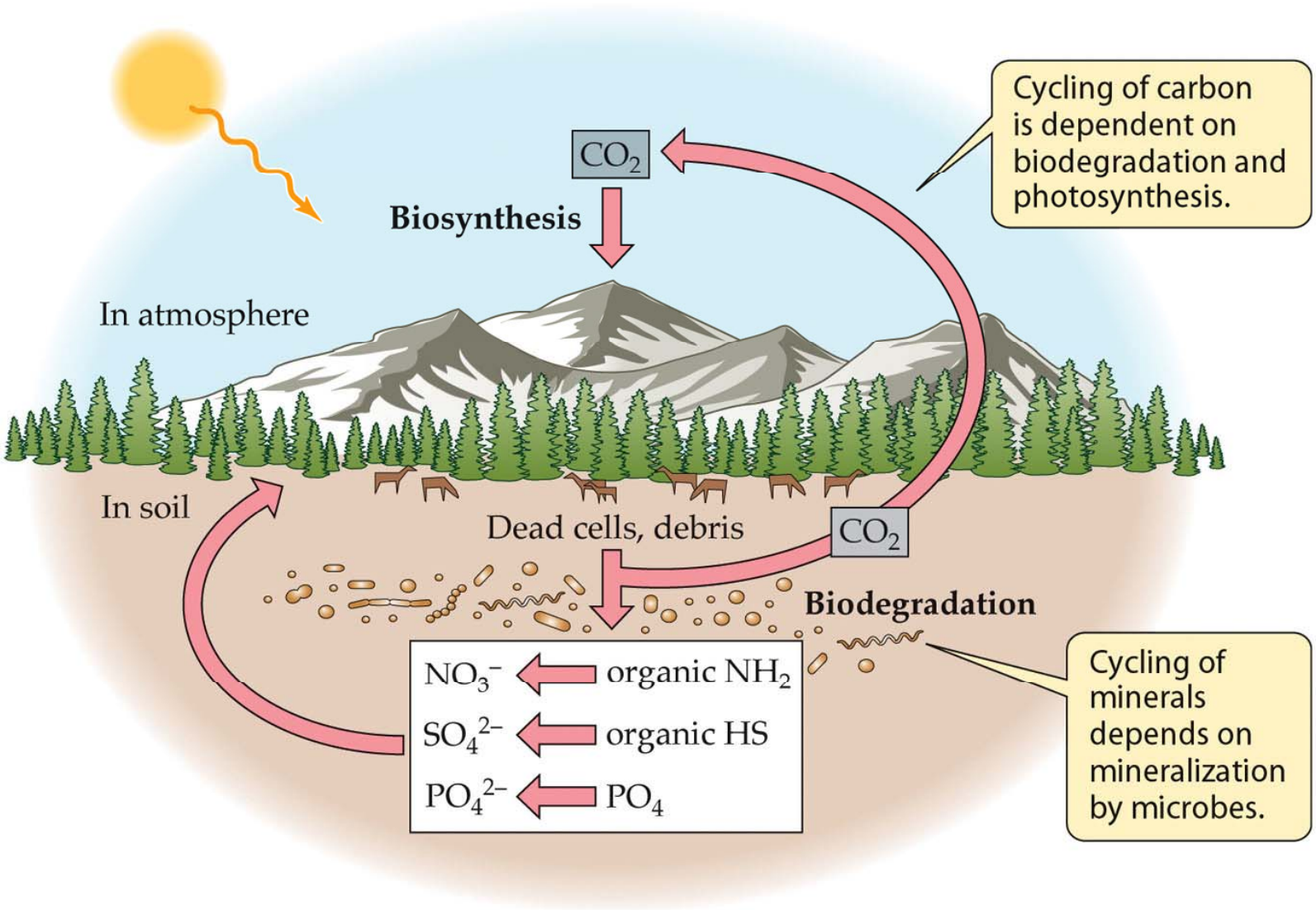


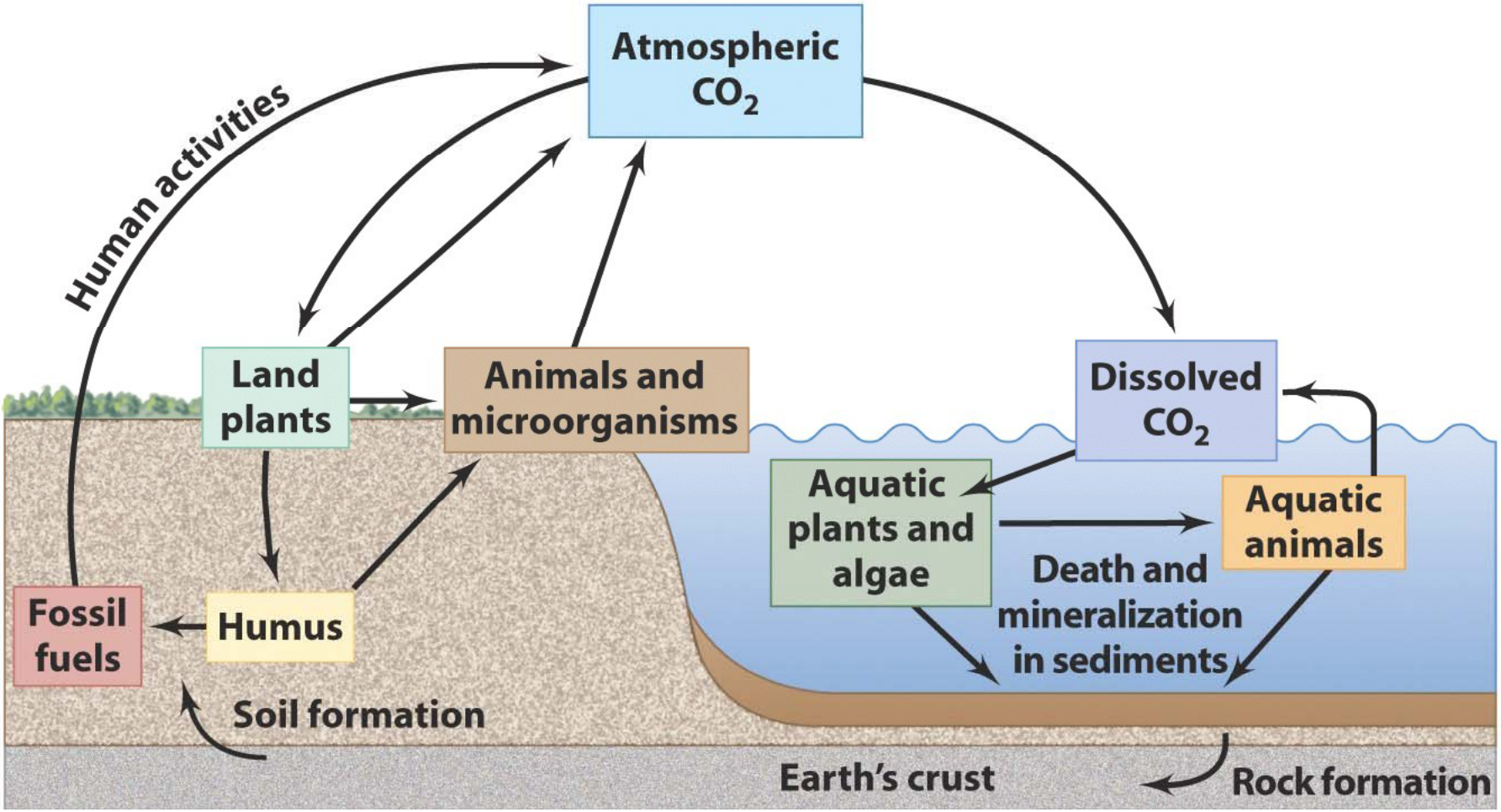
Figure 3.6 Seasonal fluctuations in the concentration of atmospheric CO_2 (1981–1984), shown as a function of 10° latitudinal belts (Conway et al. 1988). Note the smaller amplitude of the fluctuations in the southern hemisphere, reaching peak concentrations during northern hemisphere minima.


Carbon Dioxide Variations
The Industrial Revolution Has Caused A Dramatic Rise in CO_2
400
350
300
1000
1200
1400
1600
1800
2000
Year (AD)
Interglacial
Glacial
Ice Age Cycles
400
300
200
100
0
Thousands of Years Ago
400
350
300
250
200
CO_2 Concentration (ppmv)

Balance between biosynthesis and biodegradation



The carbon cycle, closely connected with oxygen cycle



Most carbon in carbonate rocks & sediments

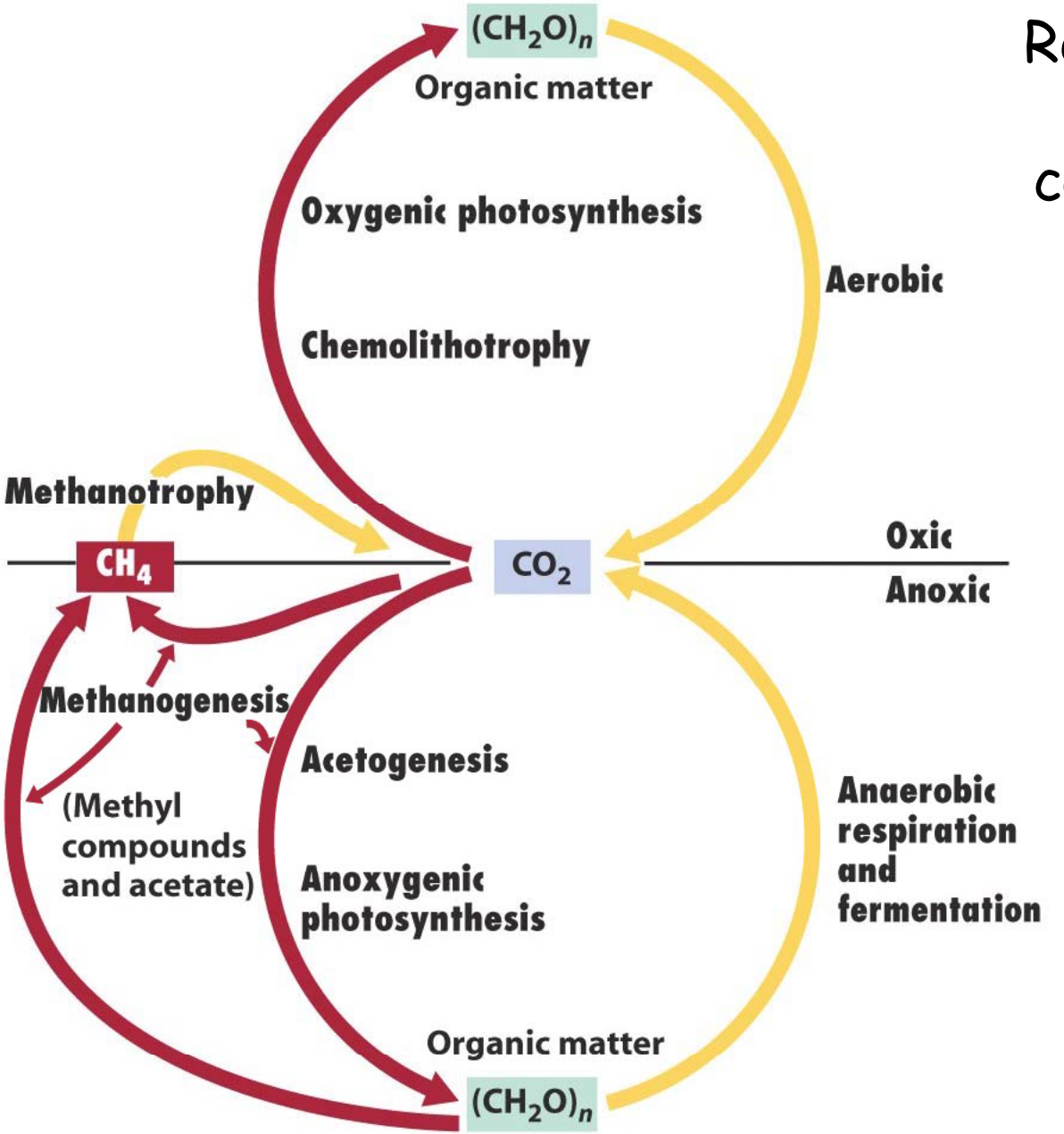
Table 19.3 Major carbon reservoirs on Earth

Reservoir	Carbon (gigatons)[a]	Percent of total carbon on Earth
Oceans	38×10^3 (>95% is inorganic C)	0.05
Rocks and sediments	75×10^6 (>80% is inorganic C)	>99.5[b]
Terrestrial biosphere	2×10^3	0.003
Aquatic biosphere	1–2	0.000002
Fossil fuels	4.2×10^3	0.006
Methane hydrates	10^4	0.014
Atmosphere	**720**	**0.005**

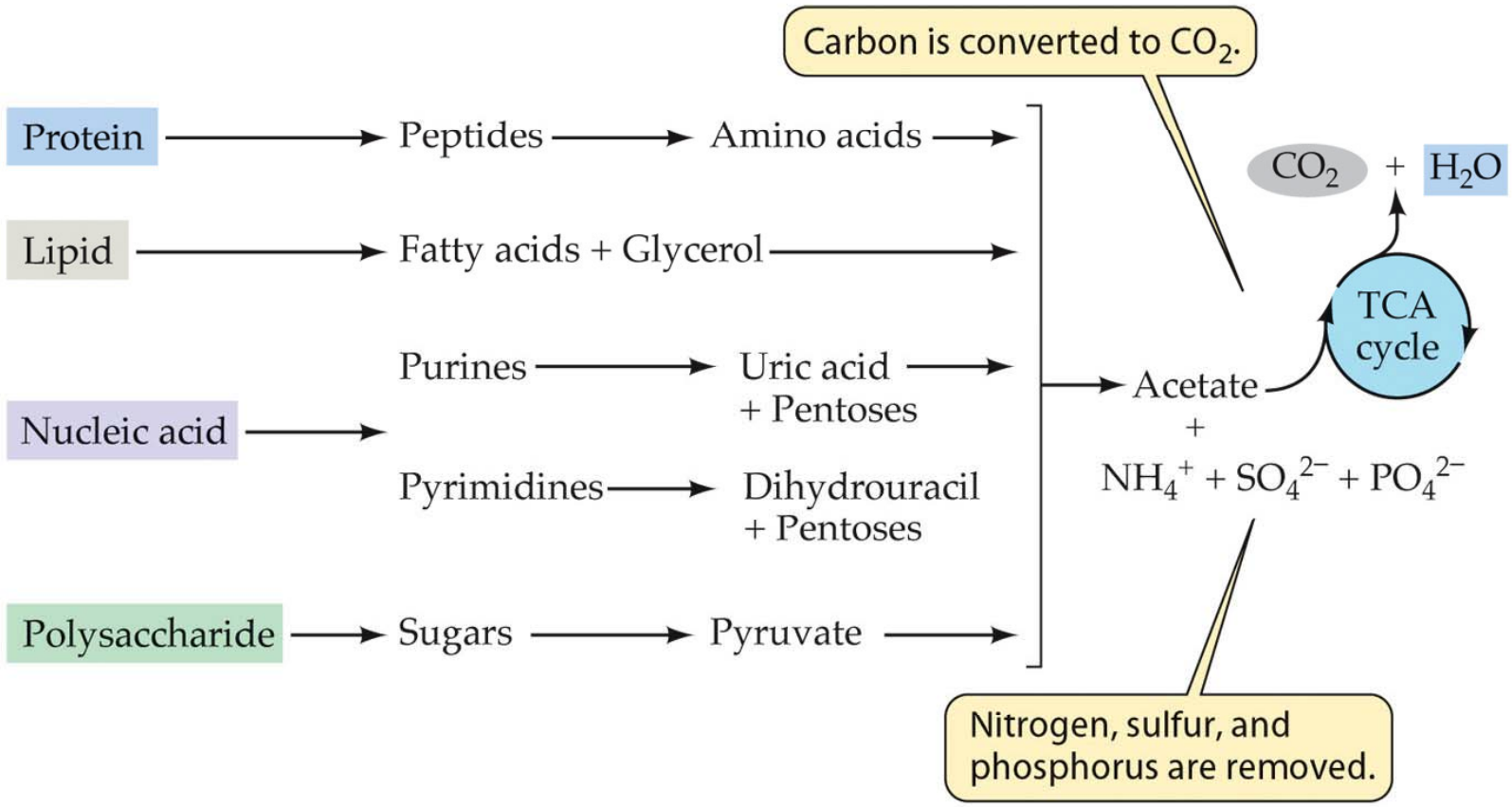
[a] One gigaton is 10^9 tons. Data adapted from *Science 290*:291–295 (2000).

[b] Much of the organic carbon is in prokaryotic cells.

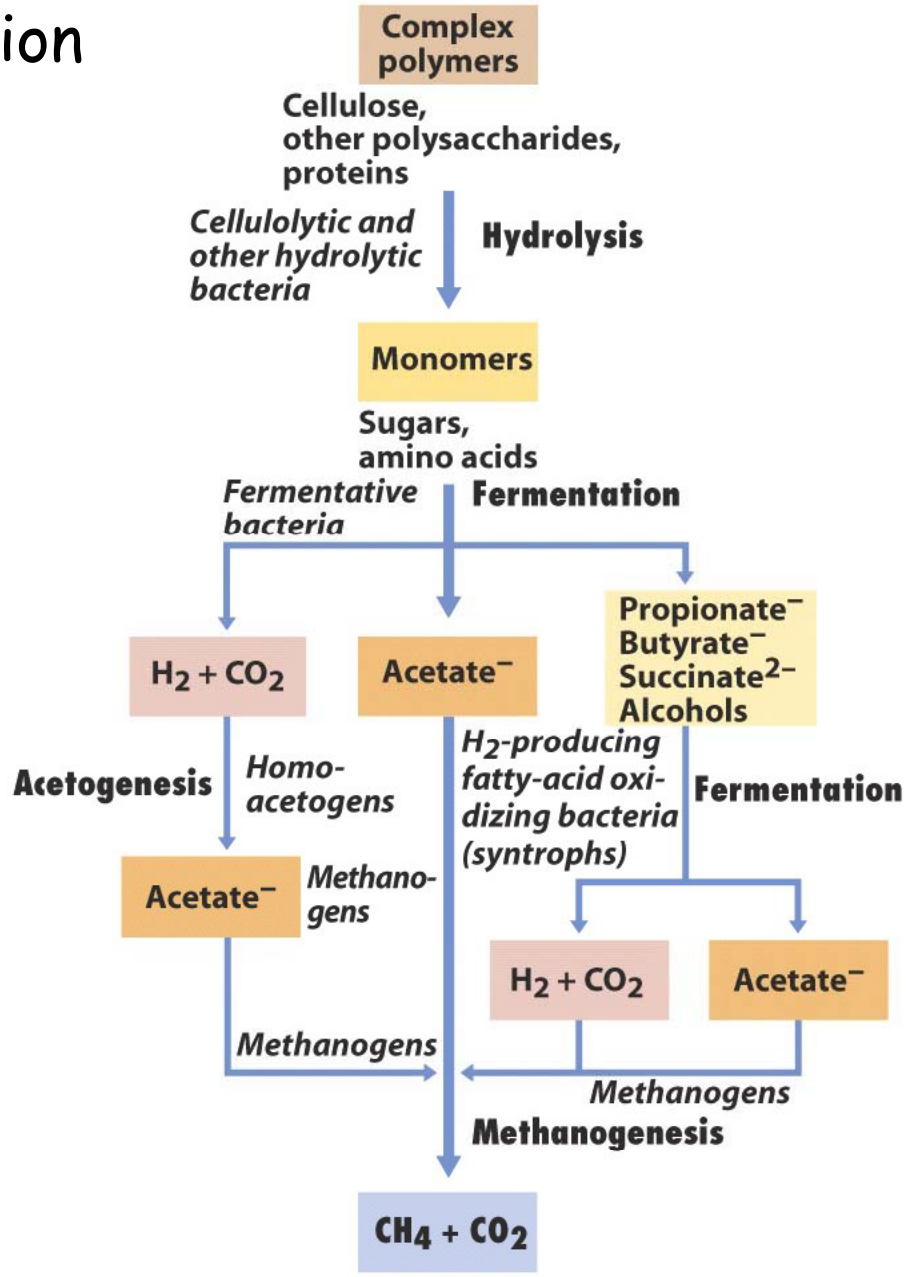
Redox states for the carbon cycle



Fate of major biomolecules



Anoxic decomposition



Options for a microbial community in aquatic sediments: one microbe's waste is another microbe's treasure!

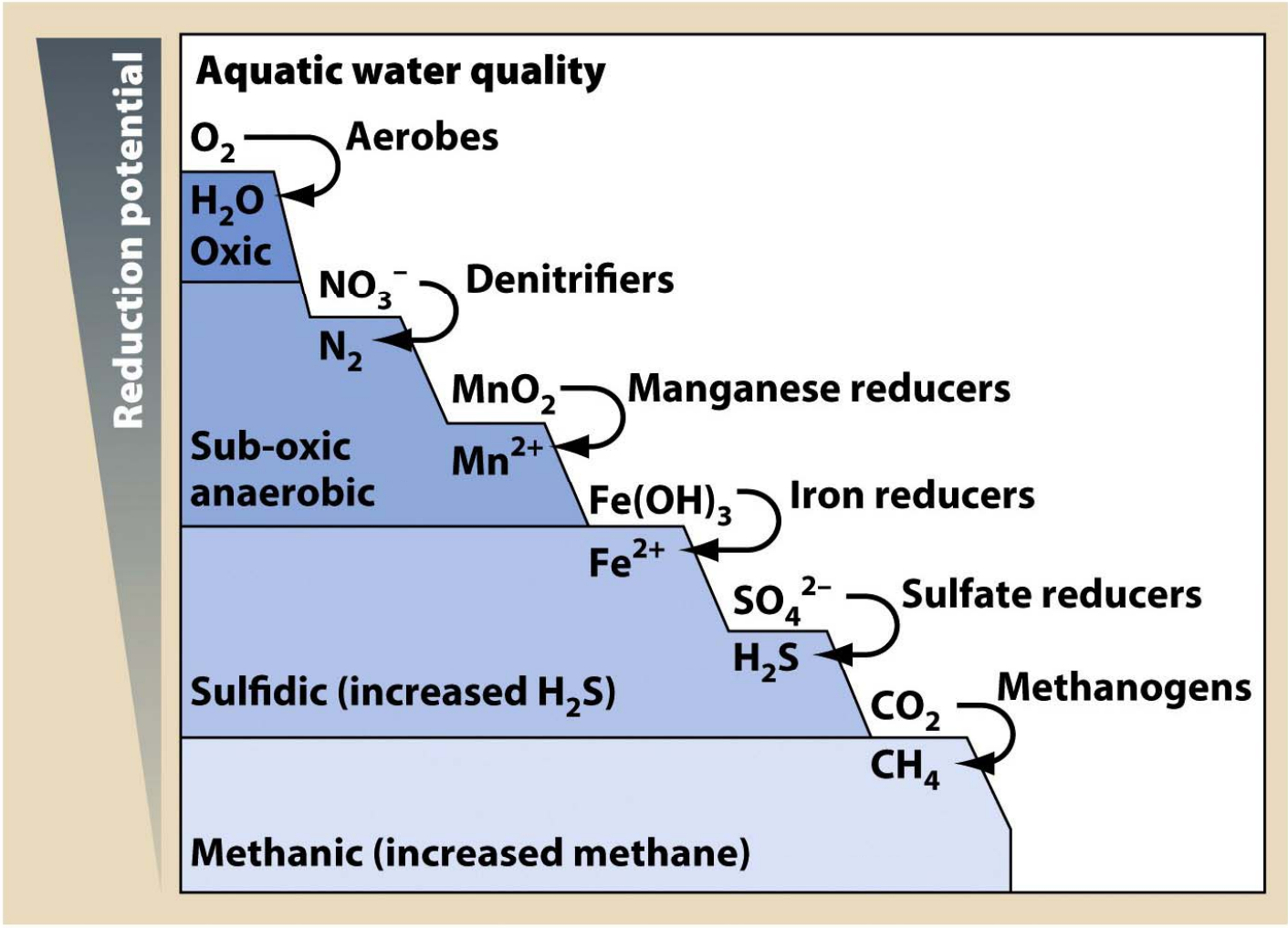


Figure 14.21 Microbiology: An Evolving Science

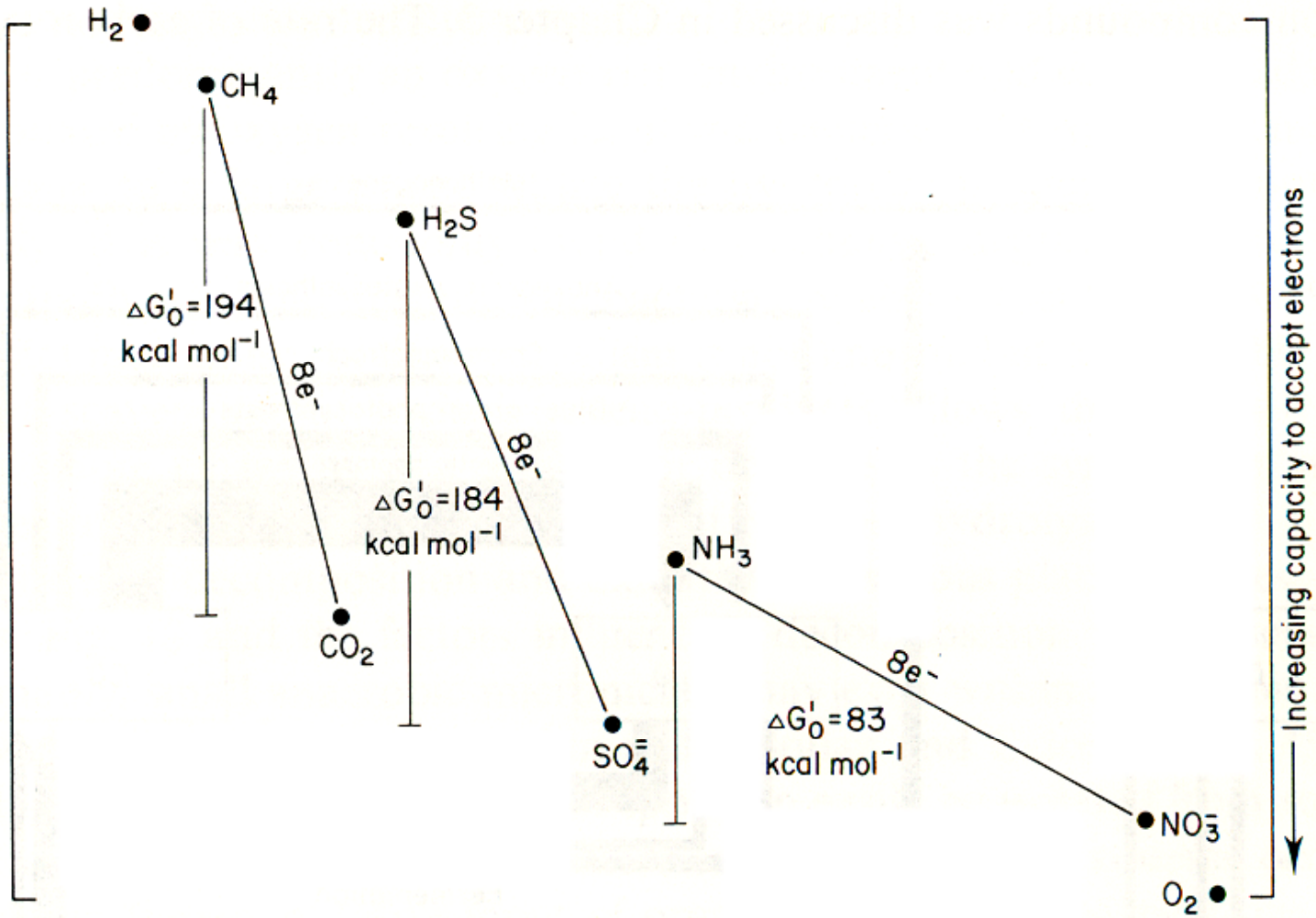


Fig. 22. A comparison between C, S and N oxidation/reductions. The most reduced and the most oxidized compounds of the C, S and N cycles are arranged in pairs, separated by a distance which represents an 8 e^- difference between the extremes. Given vertically are the $G'_\circ$ for the oxidation, by O_2, of the reduced form. There is a decreasing energy yield through the series C, S to N which is represented by the vertical distance between the oxidized and the reduced forms. The location of the lines relative to each other is only approximately correct and is designed to illustrate the decrease in reducing potential through the series H_2, CH_4, H_2S to NH_3 and the increase in oxidizing potential through the series CO_2, SO_4^{2-}, NO_3^- to O_2.

Take Home Message

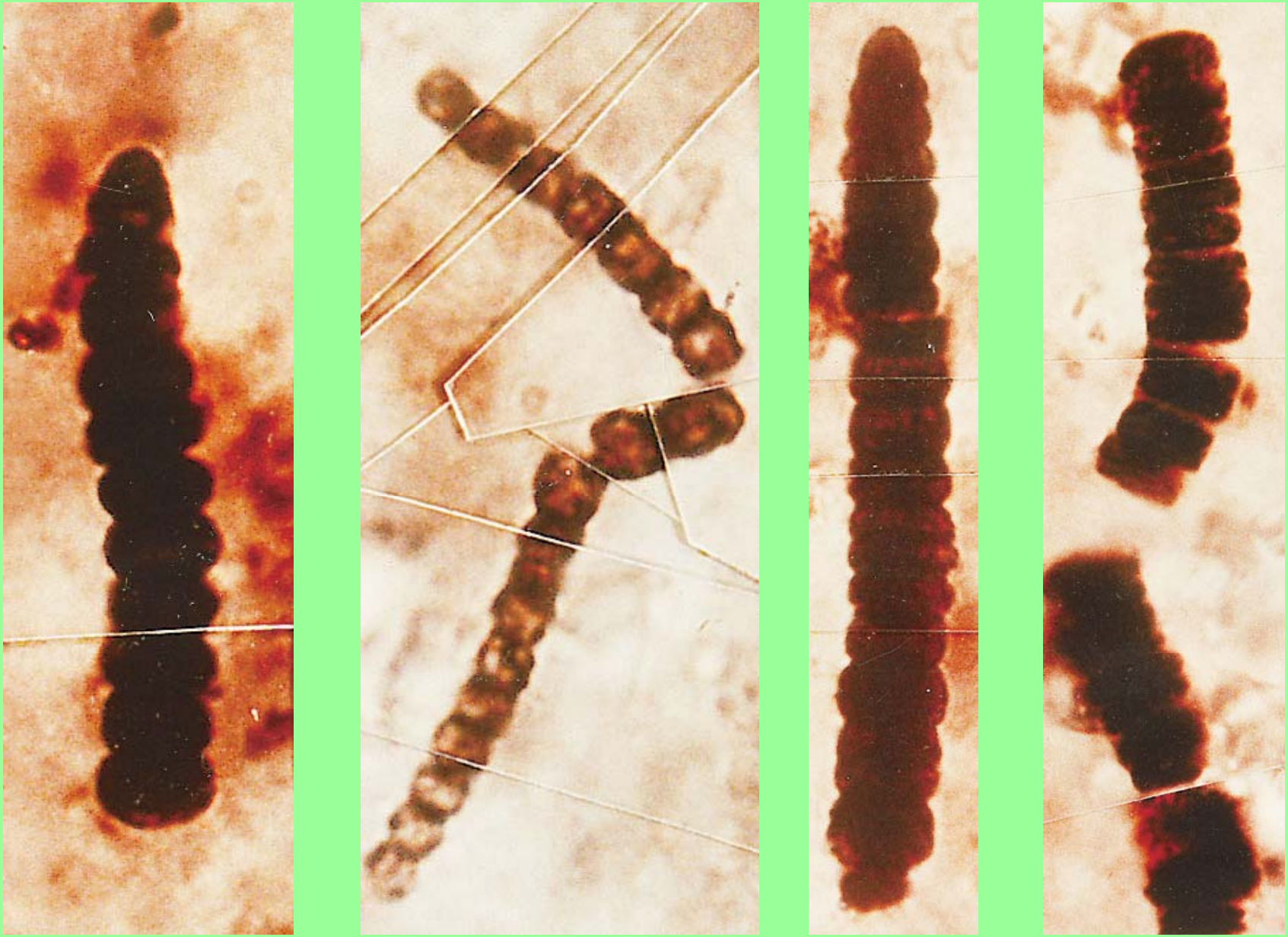
- The oxygen and carbon cycles are interconnected through the complementary activities of autotrophic and heterotrophic organisms.

- Microbial decomposition is the single largest source of CO_2 released to the atmosphere.

Microbes and Origins of Life

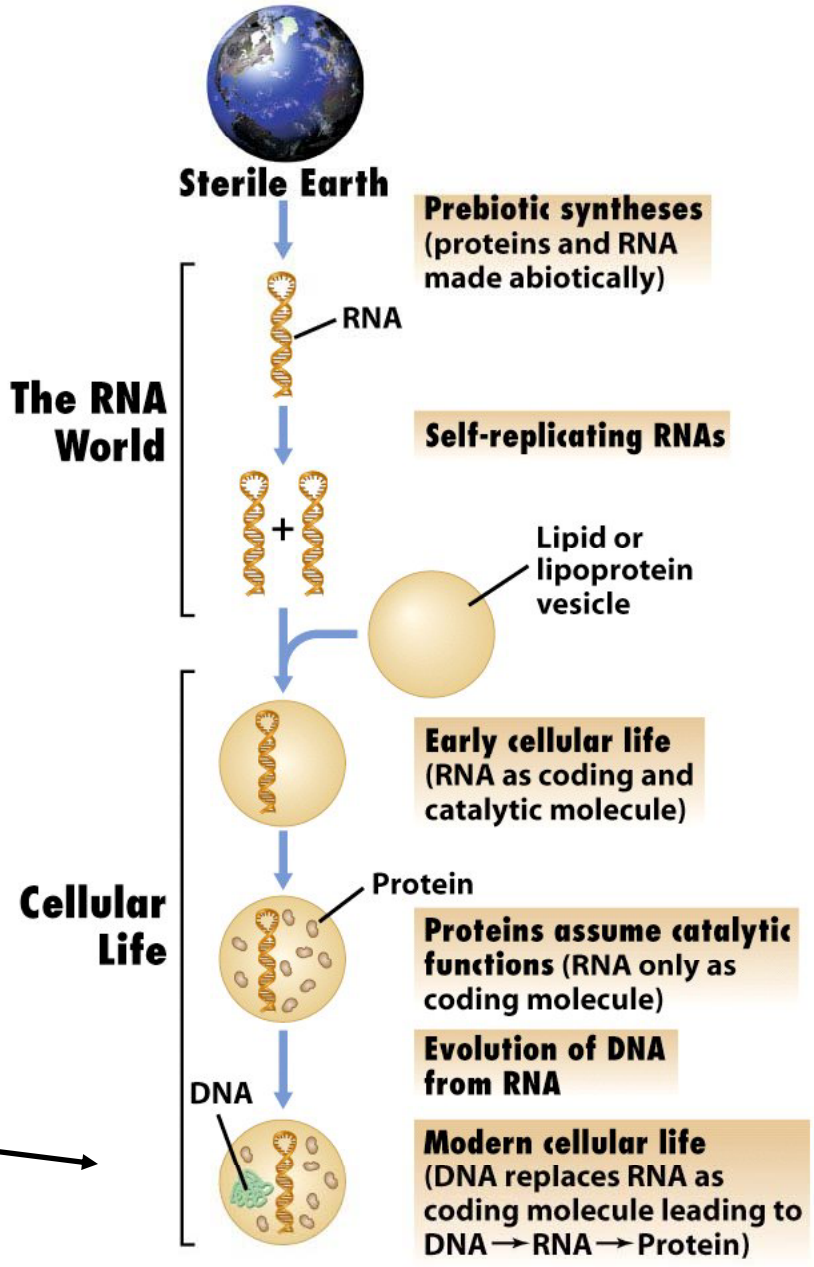
Evolution has occurred almost elusively in a microbial world !!!

Oldest Known Fossils of Living Organisms (~3500 Mya)



Living Columnar Stromatolites, Shark Bay, Western Australia

Modern Stromatolites from Yellowstone Natl. Park


Sterile Earth
Prebiotic syntheses (proteins and RNA made abiotically)
RNA
The RNA World
Self-replicating RNAs
+
Lipid or lipoprotein vesicle
Early cellular life (RNA as coding and catalytic molecule)
Protein
Cellular Life
Proteins assume catalytic functions (RNA only as coding molecule)
Evolution of DNA from RNA
DNA
Modern cellular life (DNA replaces RNA as coding molecule leading to DNA → RNA → Protein)

LUCA

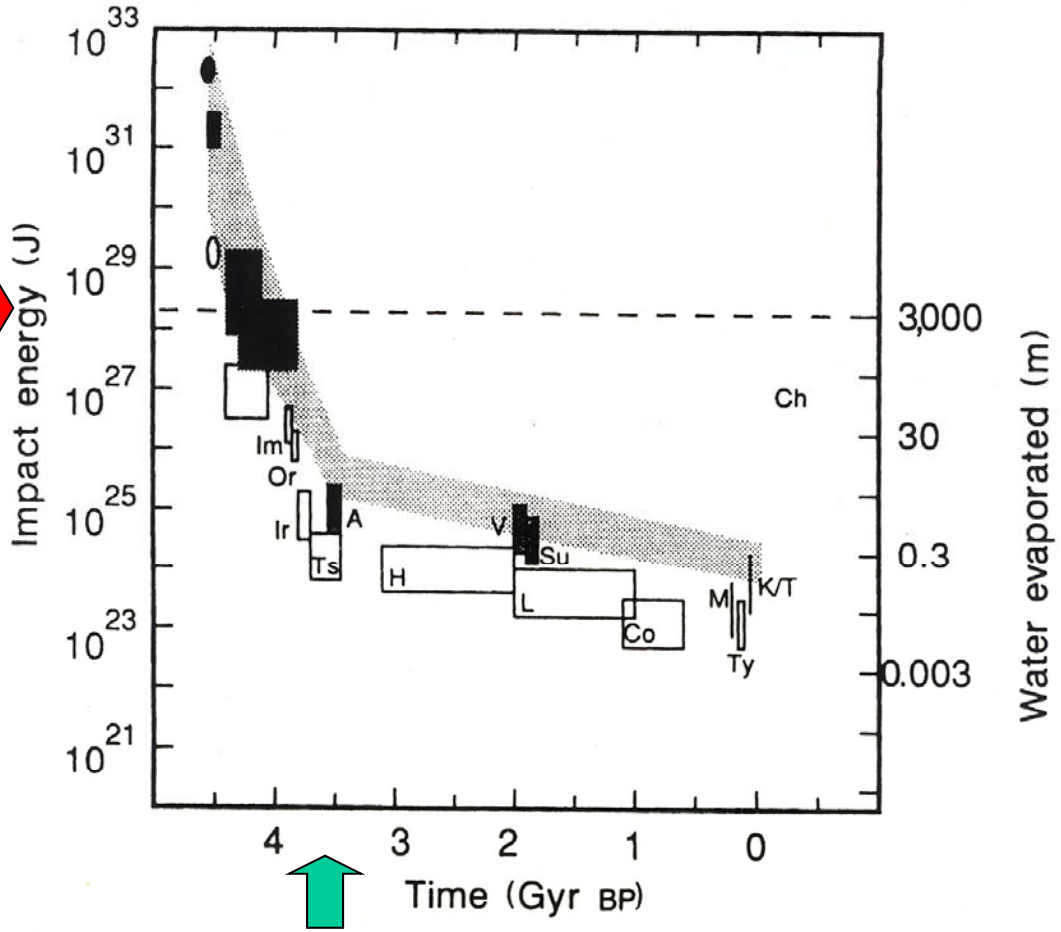
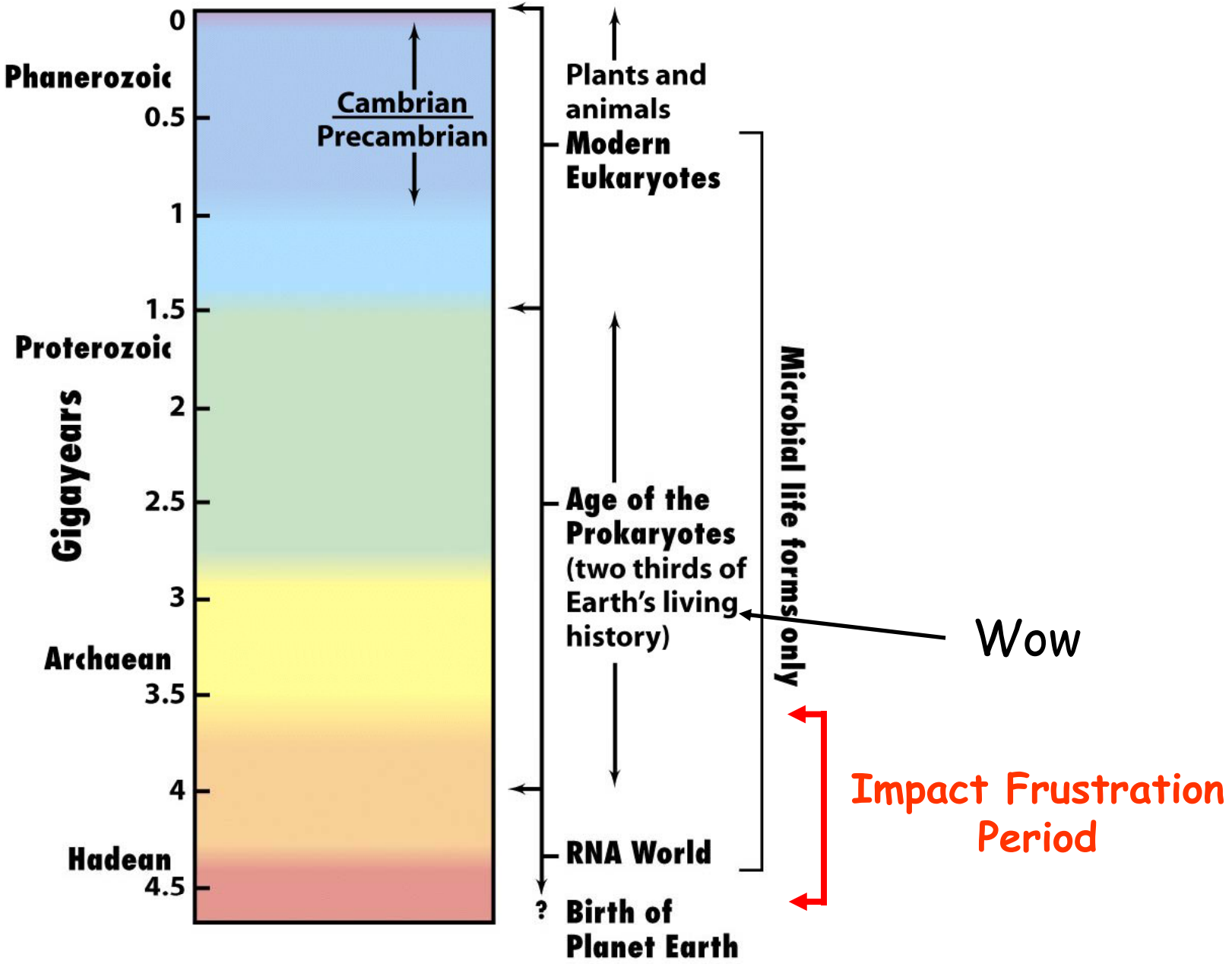


FIG. 1 The largest impacts on Earth and Moon. Open boxes are lunar, filled boxes terrestrial. Lunar craters are Tycho, Copernicus, Langrenus, Hausen, Tsiolkovski, Iridum, Orientale and Imbrium. Terrestrial events are the K/T impact, Manicougan, Sudbury, Vredevort and an impact energy corresponding to the thickness of Archaean spherule beds. Ovals are self energies of formation; the early box refers to a possible Moon-forming impact. Impact estimates between 3.8 and 4.4 Gyr are discussed in the text. The stippled region for Earth is inferred from these data. The depth of ocean vaporized by the impact is also given; the dashed line corresponds to an ocean-vaporizing impact. A possible but extremely unlikely collision with Chiron is placed safely in the future.

Impact Frustration period forces origins of life into a narrow time period to have gotten started!

Hydrothermal vents may have served as zones of refuge.


0
Phanerozoic
0.5
Cambrian
Precambrian
1
1.5
Proterozoic
2
Gigayears
2.5
3
Archaean
3.5
4
Hadean
4.5
Plants and animals
Modern Eukaryotes
Age of the Prokaryotes (two thirds of Earth's living history)
RNA World
? Birth of Planet Earth
Microbial life forms only
Wow
Impact Frustration Period

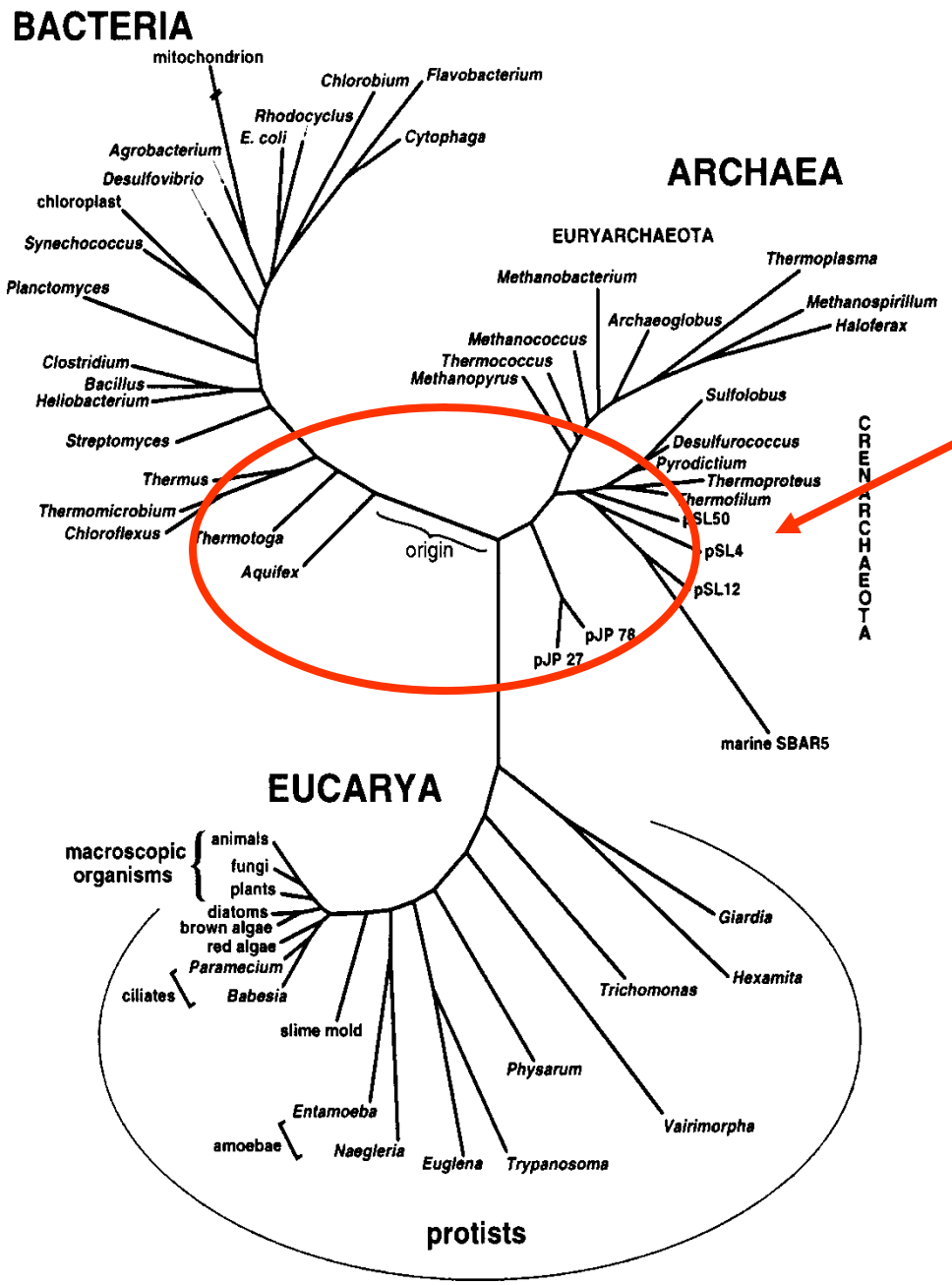
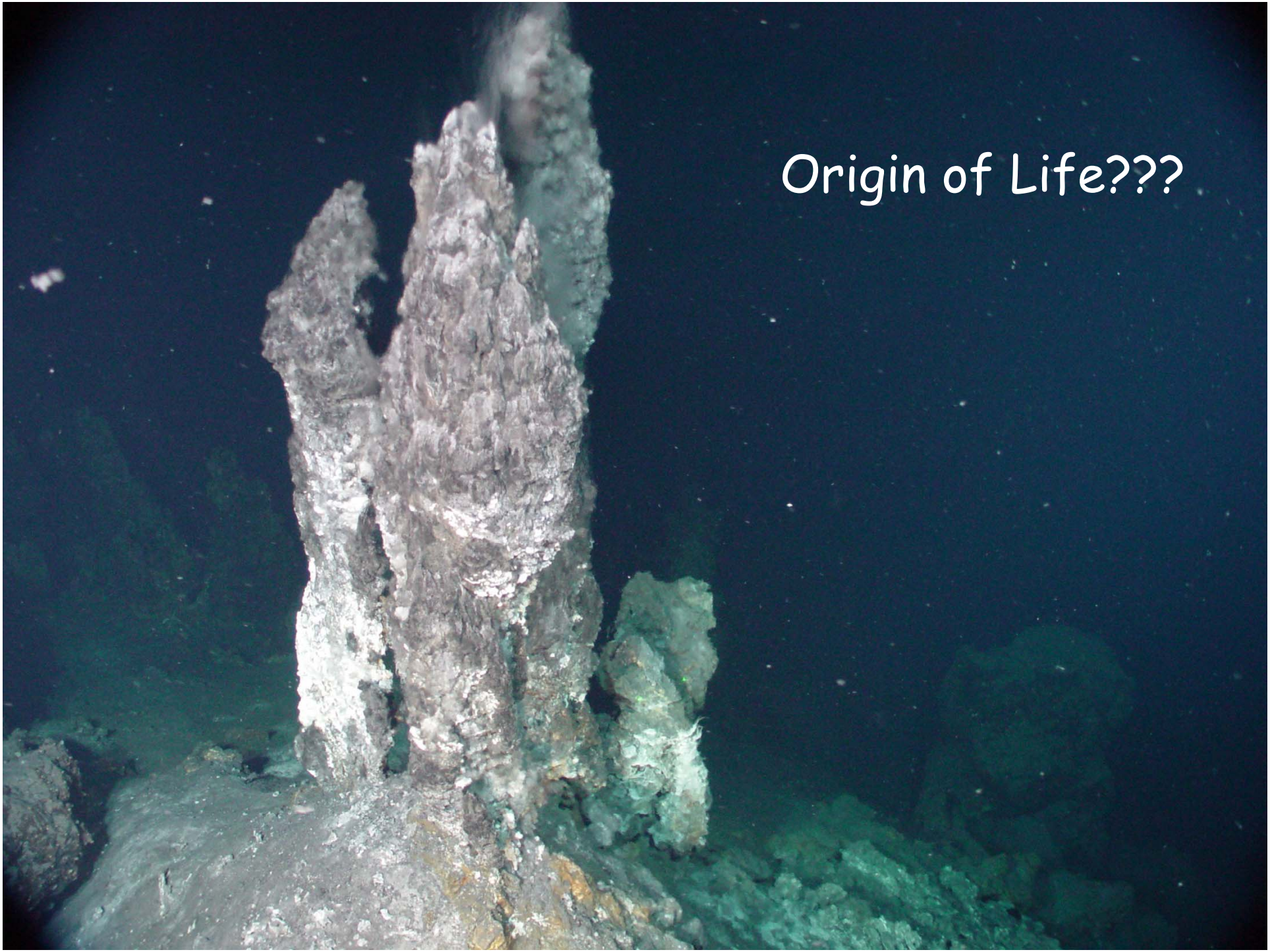


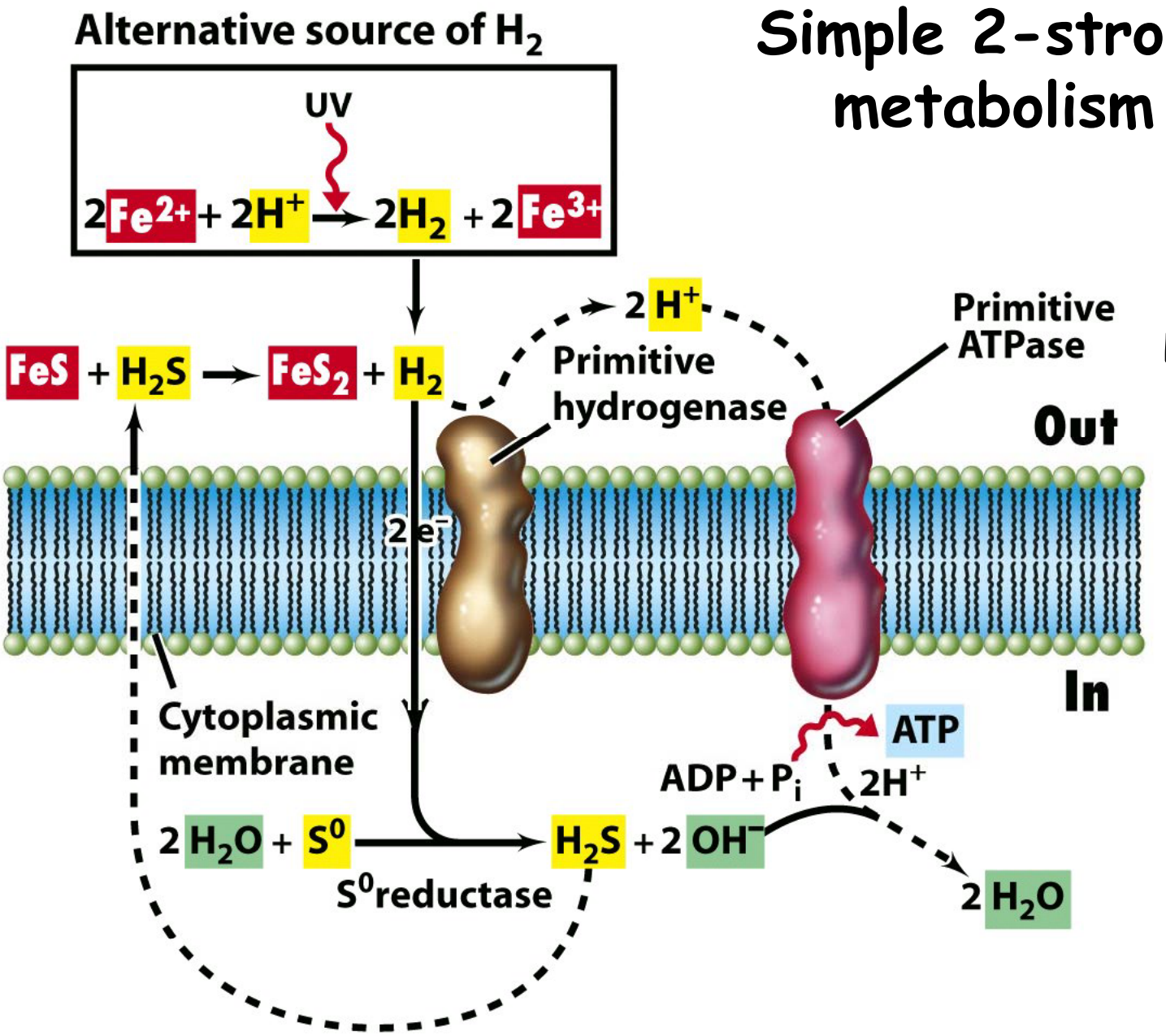
Figure 1. Diagrammatic "Universal" phylogenetic tree of life, based on small-subunit ribosomal RNA sequences. Based on analyses of Barns et al. (1996b), Olsen et al. (1994), and Sogin (1994).

Almost all are Thermophiles!

Hot Start Hypothesis

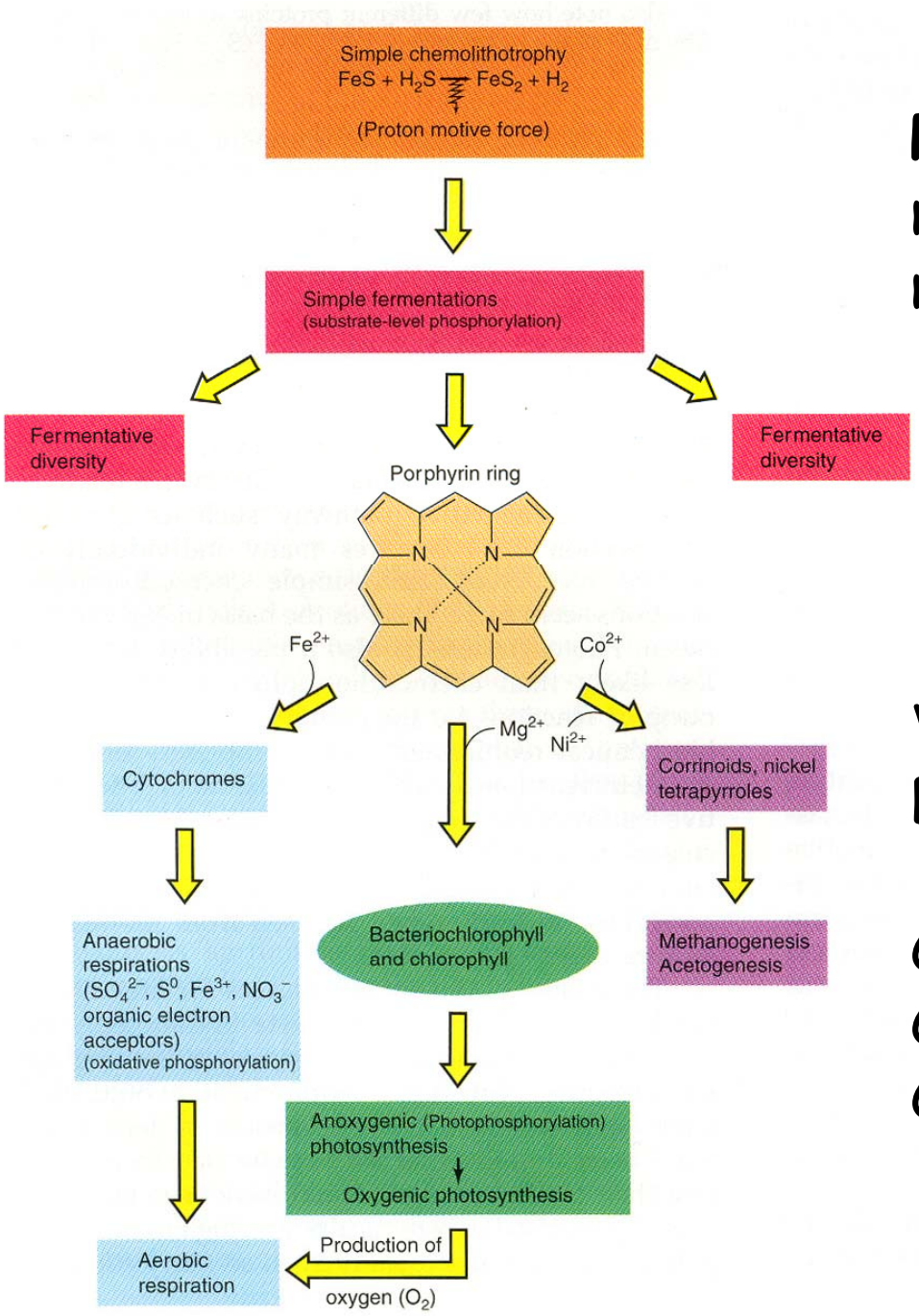

Origin of Life???

Simple 2-stroke metabolism



Chemotrophy or Phototrophy???

Hydrogenase or Rhodopsin???



Porphyrin Ring opens many possibilities for metabolic pathways!!!

Which ones are **Domain specific**?

Cytochromes: Bacteria…
Chlorophyll: Bacteria…
Corrinoids: Archaea only