Table 17.2. Normal Oxidation-Reduction Potentials of Some Biologically Important Systems at pH 7.0

SYSTEM	E'_0	T IN °C.
Ketoglutarate ⇌ succinate + CO_2 + $2H^+$ + 2e	−0.68	—‡
Ferredoxin	−0.432	—§
Formate ⇌ CO_2 + H_2	−0.420	38
H_2 ⇌ $2H^+$ + 2e	−0.414	25
NADH + H^+ ⇌ NAD^+ + $2H^+$ + 2e	−0.317	30†
NADPH + H^+ ⇌ $NADP^+$ + $2H^+$ + 2e	−0.316	30†
Horseradish oxidase	−0.27	—†
$FADH_2$ ⇌ FAD + $2H^+$ + 2e	−0.219	30†
$FMNH_2$ ⇌ FMM + $2H^+$ + 2e	−0.219	30†
Lactate ⇌ pyruvate + $2H^+$ + 2e	−0.180	35
Malate ⇌ oxaloacetate + $2H^+$ + 2e	−0.102	37
Reduced flavin enzyme ⇌ flavin enzyme + $2H^+$ + 2e	−0.063	38
Luciferin* ⇌ oxyluciferin + $2H^+$ + 2e	−0.050	?*
Ferrocytochrome B ⇌ ferricytochrome B + e	−0.04	25
Succinate ⇌ fumarate + $2H^+$ + 2e	−0.015	30
Decarboxylase	+0.19	—†
Ferrocytochrome C ⇌ ferricytochrome C + e	+0.26	25
Ferrocytochrome A ⇌ ferricytochrome A + e	+0.29	25
Ferrocytochrome A_3 ⇌ ferricytochrome A_3 + e	?	—‡
H_2O ⇌ ½O_2 + $2H^+$ + 2e	+0.815	25

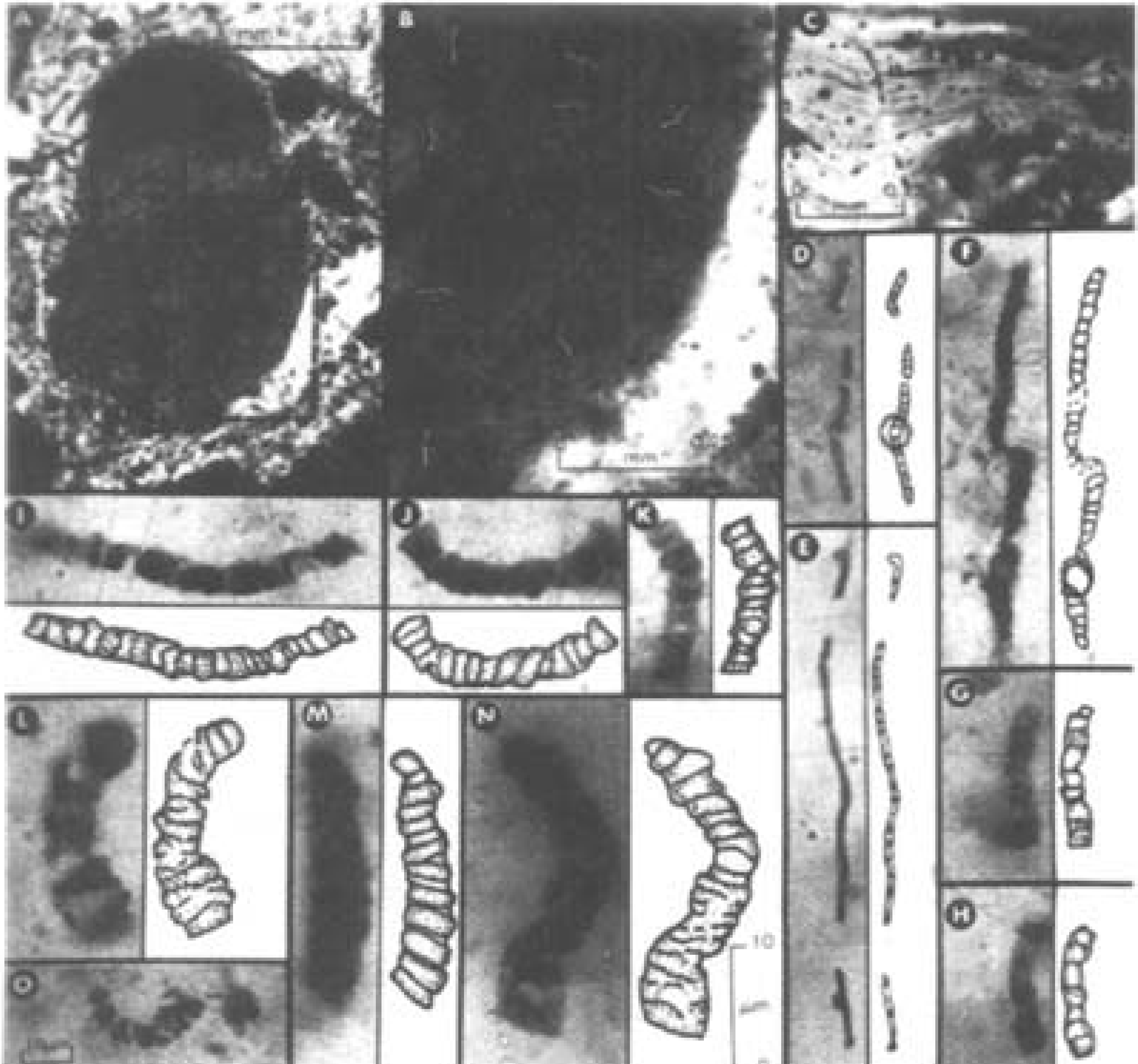
Data from Goddard, 1945. Potentials in all cases are at or near neutrality.

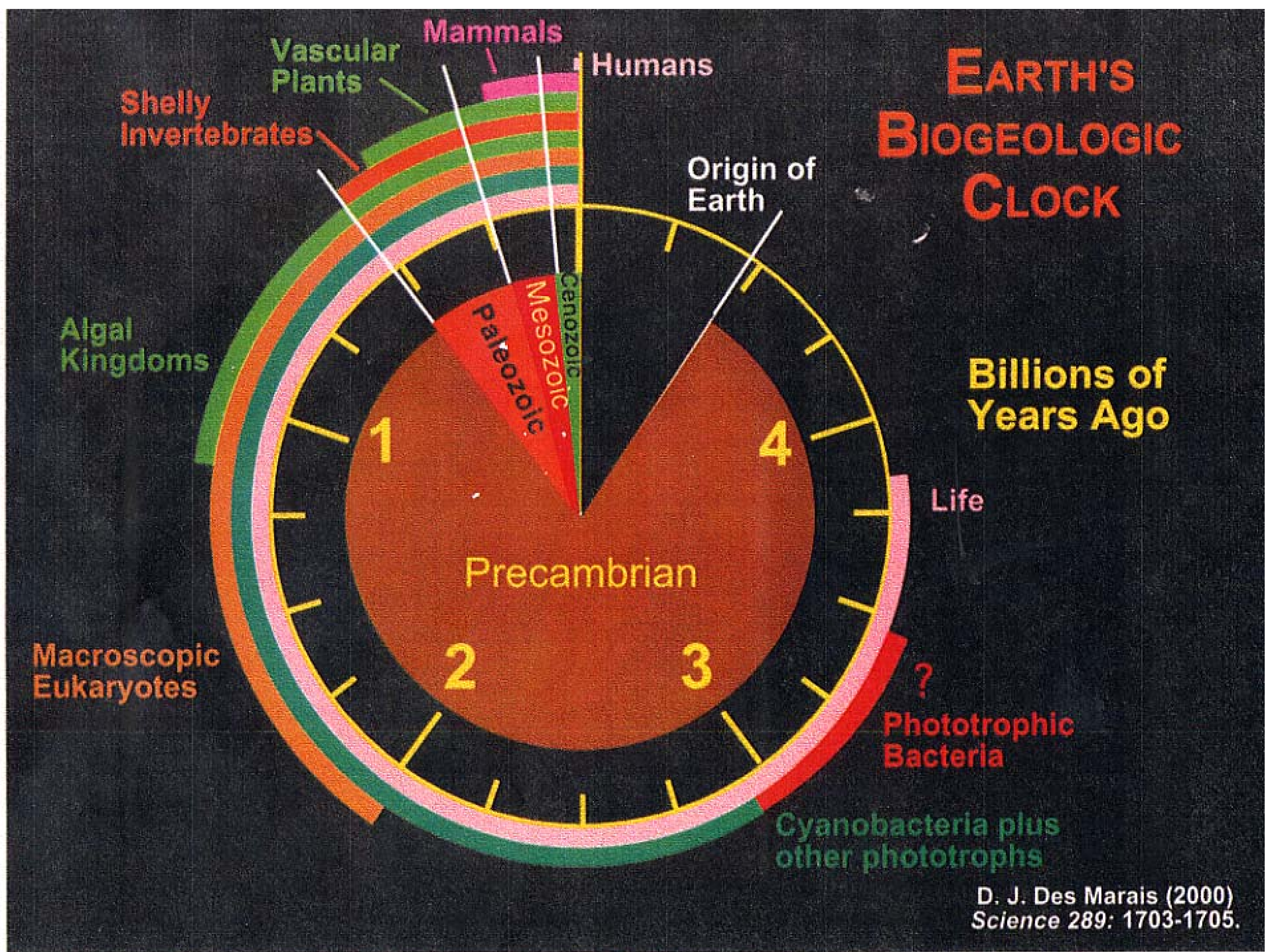
* From McElroy and Strehler, 1954: Bact. Rev. *18*.

† From Clark, 1960.

‡ From Goddard and Bonner, 1960: *In* Plant Physiology, a Treatise. Steward, ed. Academic Press, New York. Goddard and Bonner give the NADPH/$NADP^+$ system as −0.324, and NADH/NAD^+ as −0.320.

§ From Tagawa and Arnon, 1962: Nature *195*:537–543. The value cited is for spinach ferredoxin.


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
10
0


EARTH'S BIOGEOLOGIC CLOCK
Mammals
Vascular Plants
Humans
Shelly Invertebrates
Origin of Earth
Algal Kingdoms
Paleozoic
Mesozoic
Cenozoic
Billions of Years Ago
1
4
Life
Precambrian
Macroscopic Eukaryotes
2
3
?
Phototrophic Bacteria
Cyanobacteria plus other phototrophs
D. J. Des Marais (2000)
Science 289: 1703-1705.

Carbon Pools in the Major Reservoirs on Earth

Table 5.1 Carbon pools in the major reservoirs on Earth

Pools	Quantity ($\times 10^{15}$ g)
Atmosphere	720
Oceans	38,400
Total inorganic	37,400
Surface layer	670
Deep layer	36,730
Total organic	1,000
Lithosphere	
Sedimentary carbonates	>60,000,000
Kerogens	15,000,000
Terrestrial biosphere (total)	2,000
Living biomass	600–1,000
Dead biomass	1,200
Aquatic biosphere	1–2
Fossil fuels	4,130
Coal	3,510
Oil	230
Gas	140
Other (peat)	250

From: Falkowski & Raven. Aquatic Photosynthesis. p. 130 (1997)

REDOX REACTIONS ARE COUPLED ON

MICROSCOPIC SCALES

General Reaction

$$A(ox) + n\,(e^-) \longrightarrow A(red)$$

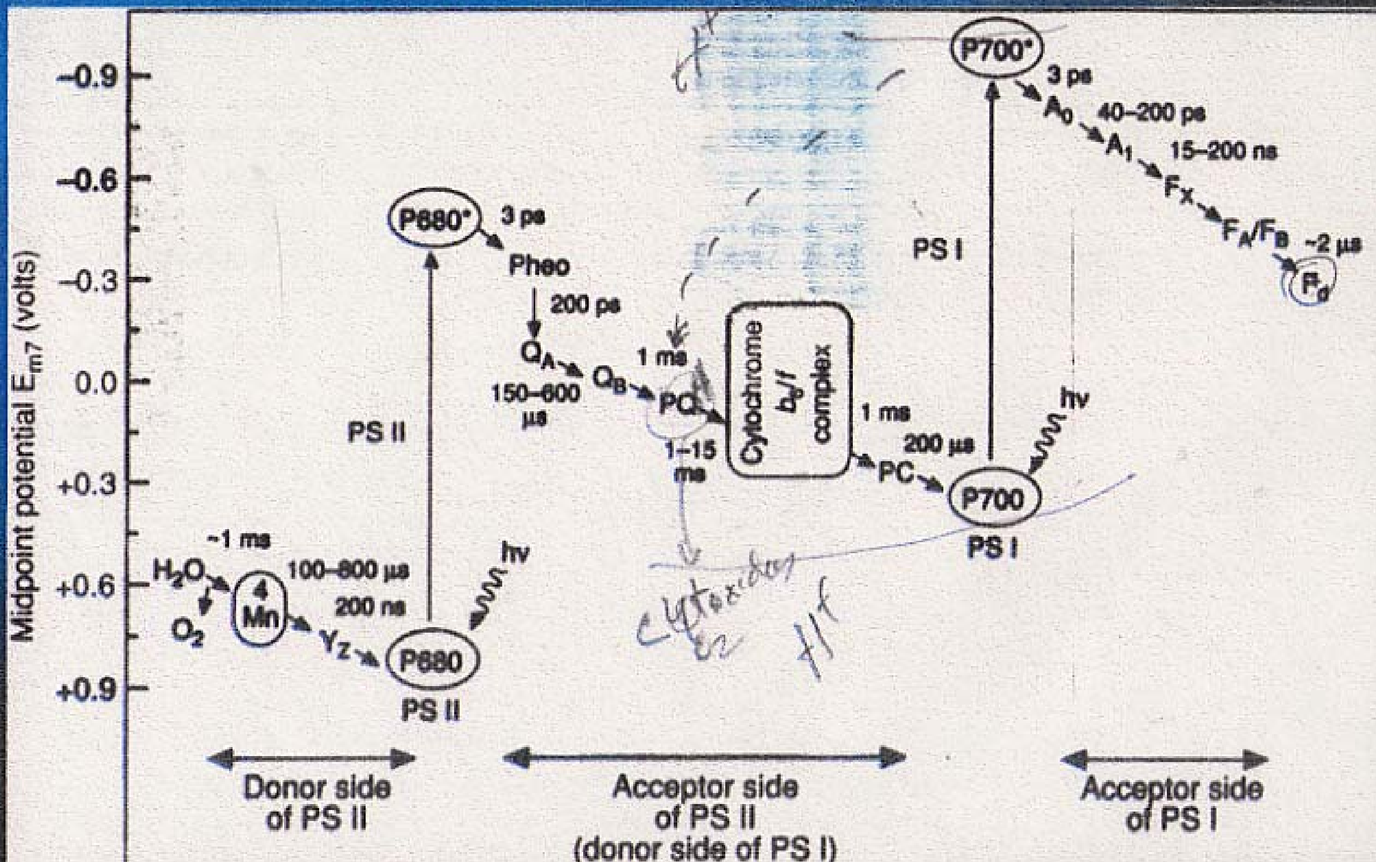
$$B(red) - n(e^-) \longrightarrow B(ox)$$

Photosynthesis

$$2H_2O + light \longrightarrow 4H^+ + 4e^- + O_2$$

$$CO_2 + 4H^+ + 4e^- \longrightarrow (CH_2O) + H_2O$$

Oxygenic Photosynthetic Electron Transport



From: Falkowski & Raven. Aquatic Photosynthesis. (1997)

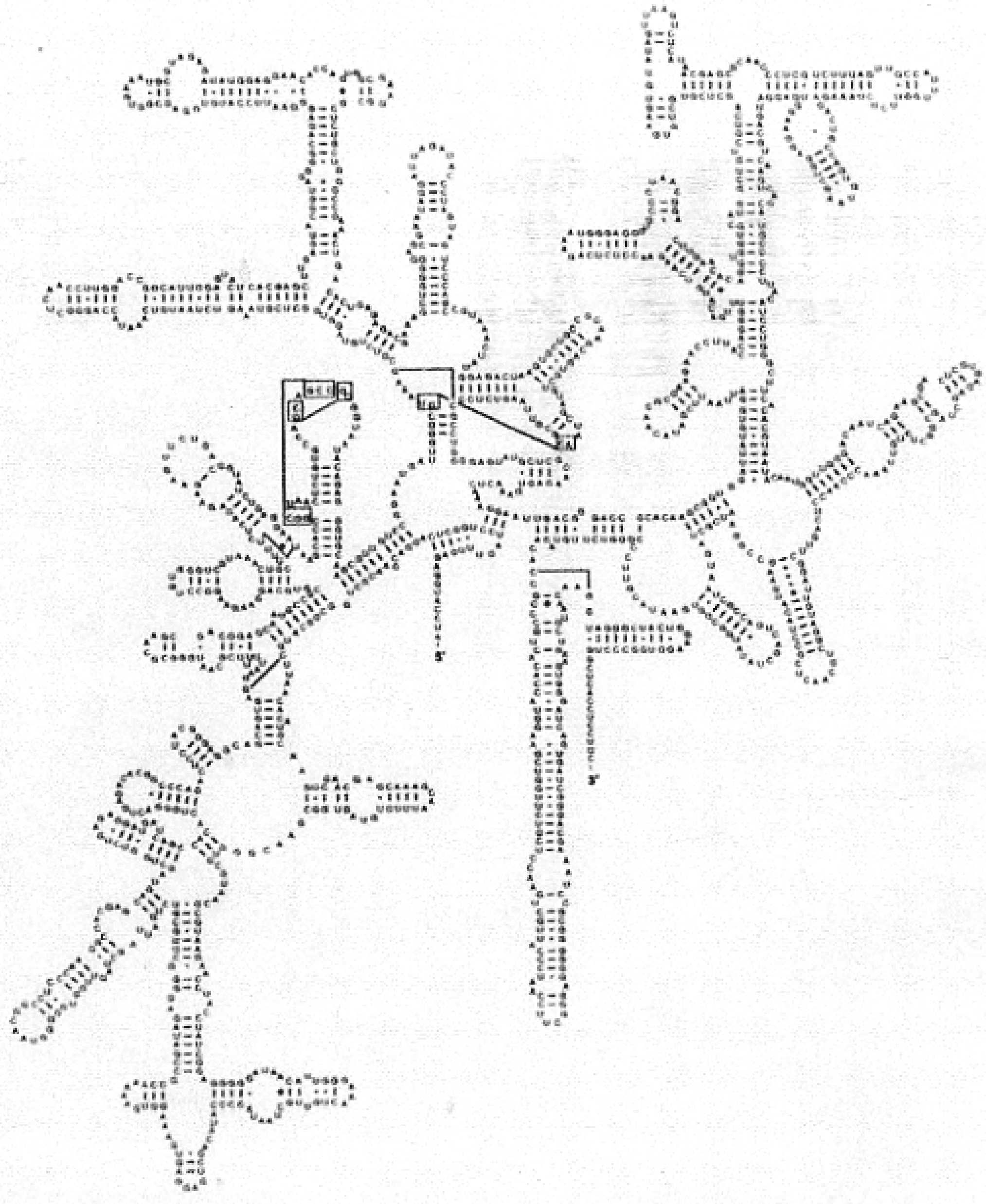
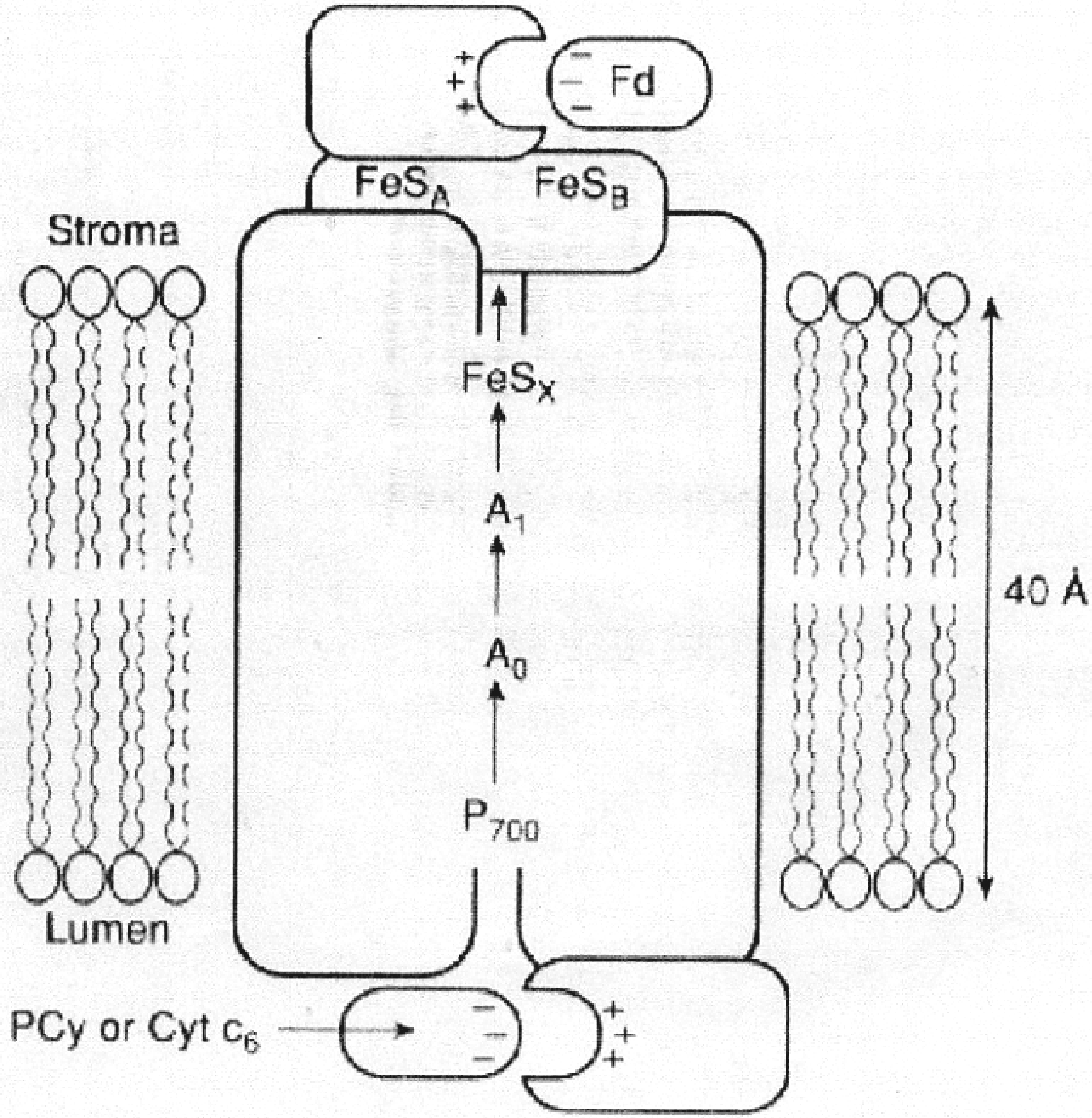


Figure 1.7 The secondary structure of the small subunit (16S) rRNA from *Chlamydomonas reinhardtii*. The structure is inferred from homology with known structures in yeast and prokaryotes. Hollow circles and unpaired regions represent areas of generally higher variability between organisms.



Fd
FeS_A
FeS_B
Stroma
FeS_X
A_1
40 Å
A_0
P_700
Lumen
PCy or Cyt c_6

The Nernst Equation

$$[A_{ox}] + n\ [e^-] + m[H^+] \longrightarrow [A_{red}]$$

where m is the number of protons involved in the reduction of A_{ox}.

The redox potential for this reaction can be calculated by:

$$E = E_{m7} + 59/n \log [A_{red}]/[A_{ox}][H^+]^m$$

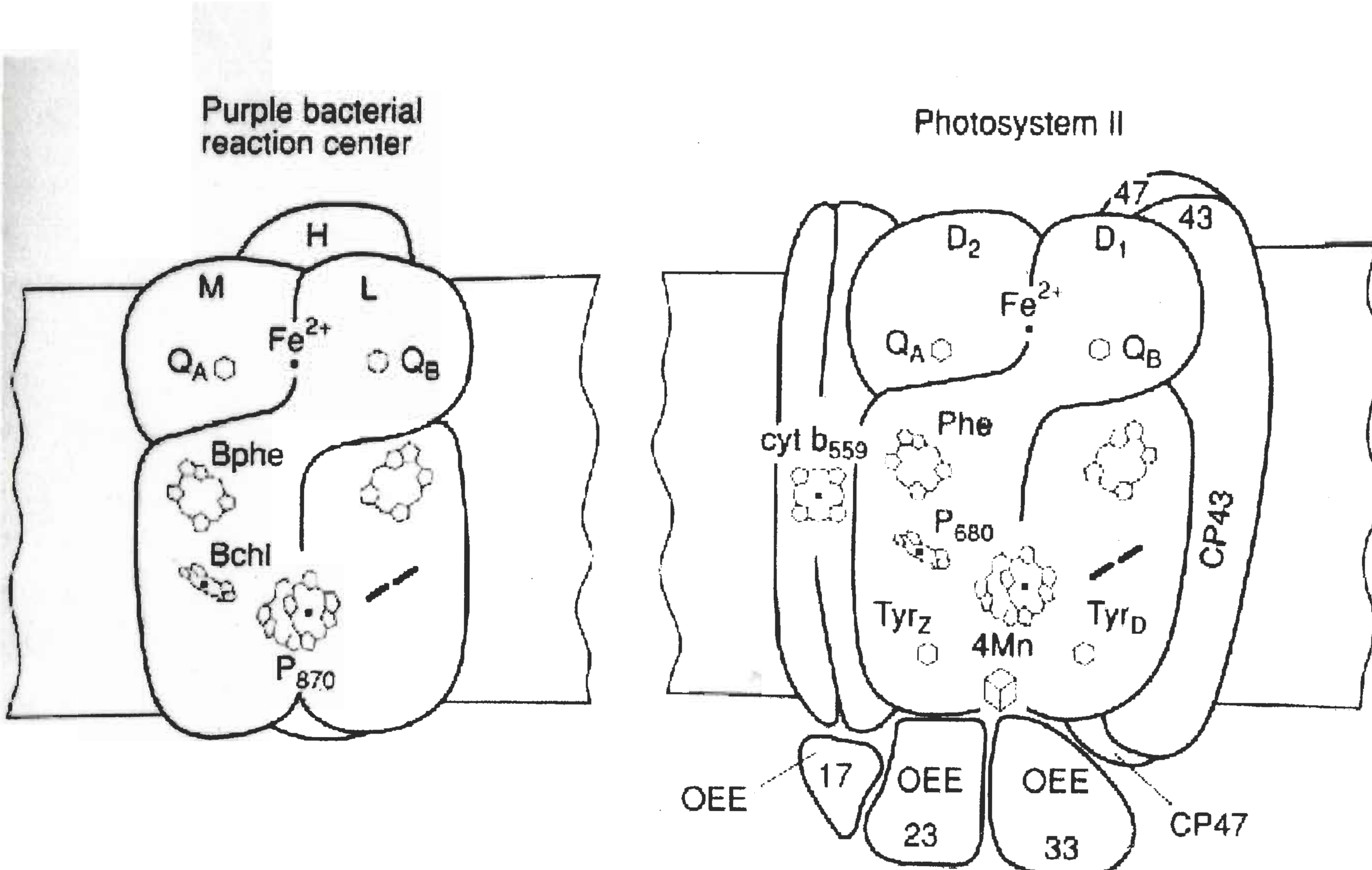
which can be rewritten as:

$$E = E_{m7} + 59/n \log ([A_{red}]/[A_{ox}]) + 59(m/n)pH$$

Table 4.1 Mid-point potentials for some common electron carriers in photosynthesis research

	ox + n(e^-) + m(H^+) ⇌ red			Change in E_m(mV) when pH increased by 1 unit
	n	m	E_{m7}(mV)	
Dithionite ox/red	1	0	−610	0
Methyl viologen ox/red	1	0	−450	0
CO_2/CH_2O	2	2	−430	−60
Ferredoxin ox/red	1	0	−430	0
$H^+/{}^1\!/_2H_2$(H_2 1 atm)	1	1	−420	−60
NAD^+/NADH	2	1	−320	−30
$NADP^+$/NADPH	2	1	−320	−30
Menaquinone/menaquinol	2	2	−74	−60
Plastoquinone/plastoquinol	2	2	−0	−60
Fumarate/succinate	2	2	+30	−60
Ubiquinone/ubiquinol	2	2	+40	−60
Ascorbate ox/red	2	1	+60	−30
PMS ox/red	2	1	+80	−30
DCPIP/$DCPIPH_2$	2	2	+220	−60
TMPD ox/red	1	0	+260	0
DAD/$DADH_2$	2	2	+275	−60
Cytochrome *f* (ox/red)	1	0	+350	0
Cytochrome c_{553} (ox/red)	1	0	+370	0
Plastocyanin (ox/red)	1	0	+380	0
Ferricyanide ox/red	1	0	+420	0
P_{700}/P^+_{700}	1	0	+480	0
O_2(1 atm)/$2H_2O$(55 M)	4	4	+840	−60
P_{680}/P^+_{680}	1	0	+1100	0

DAD is 2,3,5,6-tetramethylphenylene diamine; PMS is phenazine methosulphate; TPMD is N,N,N',N'-tetramethyl-p-phenylene diamine; DCPIP is 2,6-dichlorophenolindophenol. (Adapted from Nicholls DG and Ferguson SJ, *Bioenergetics*. London: Academic Press, 1992)



Purple bacterial reaction center
H
M
L
Fe2+
QA
QB
Bphe
Bchl
P870
Photosystem II
47
43
D2
D1
Fe2+
QA
QB
Phe
cyt b559
P680
CP43
TyrZ
TyrD
4Mn
OEE
17
OEE
23
OEE
33
CP47

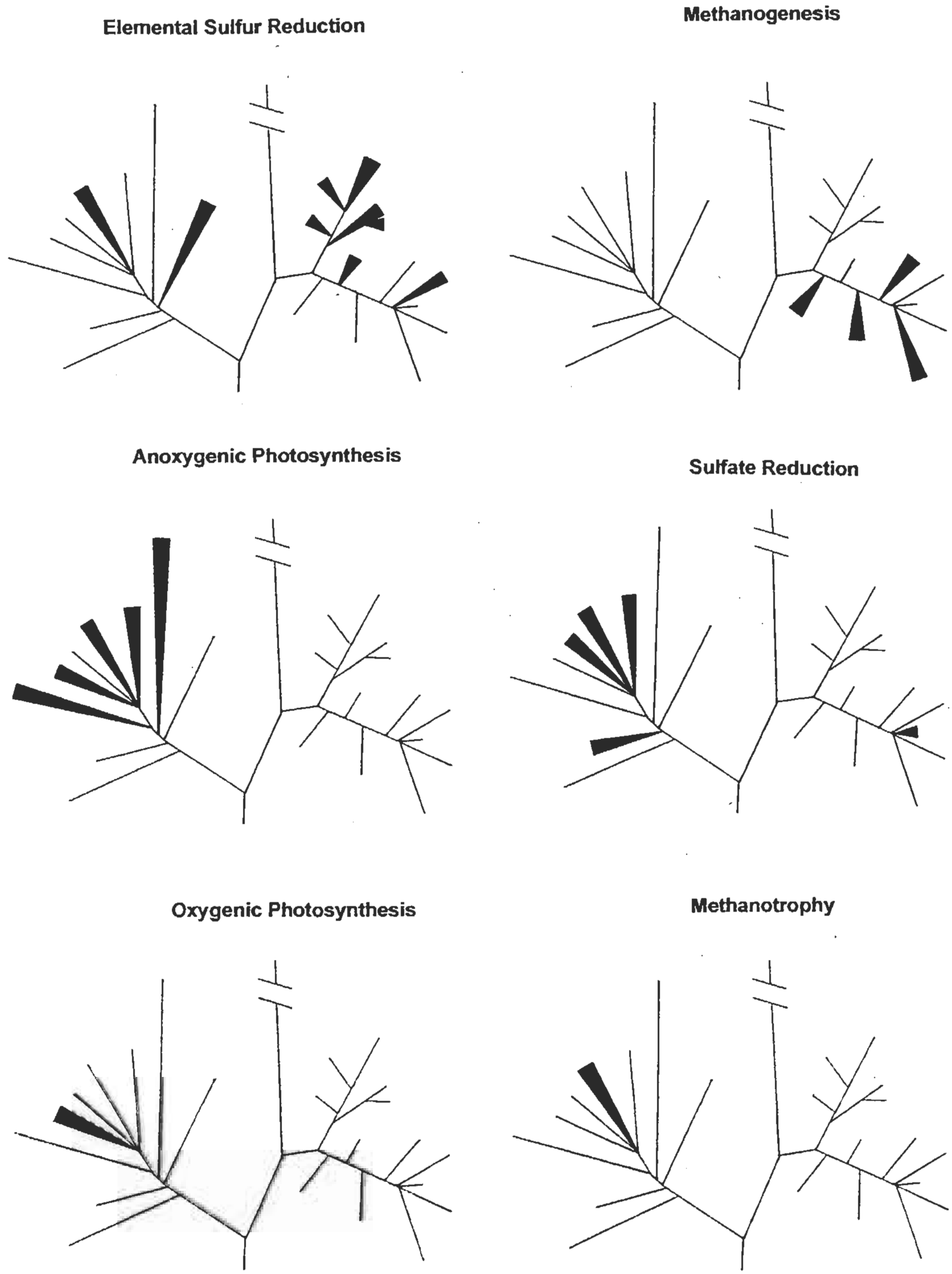
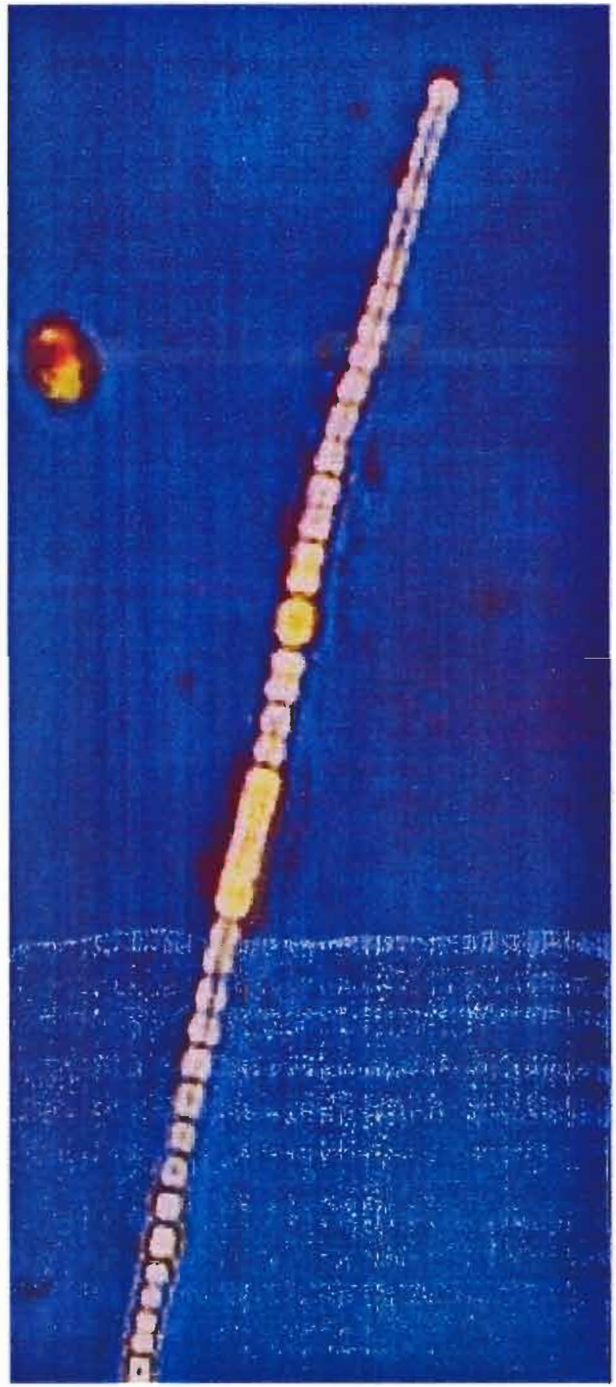
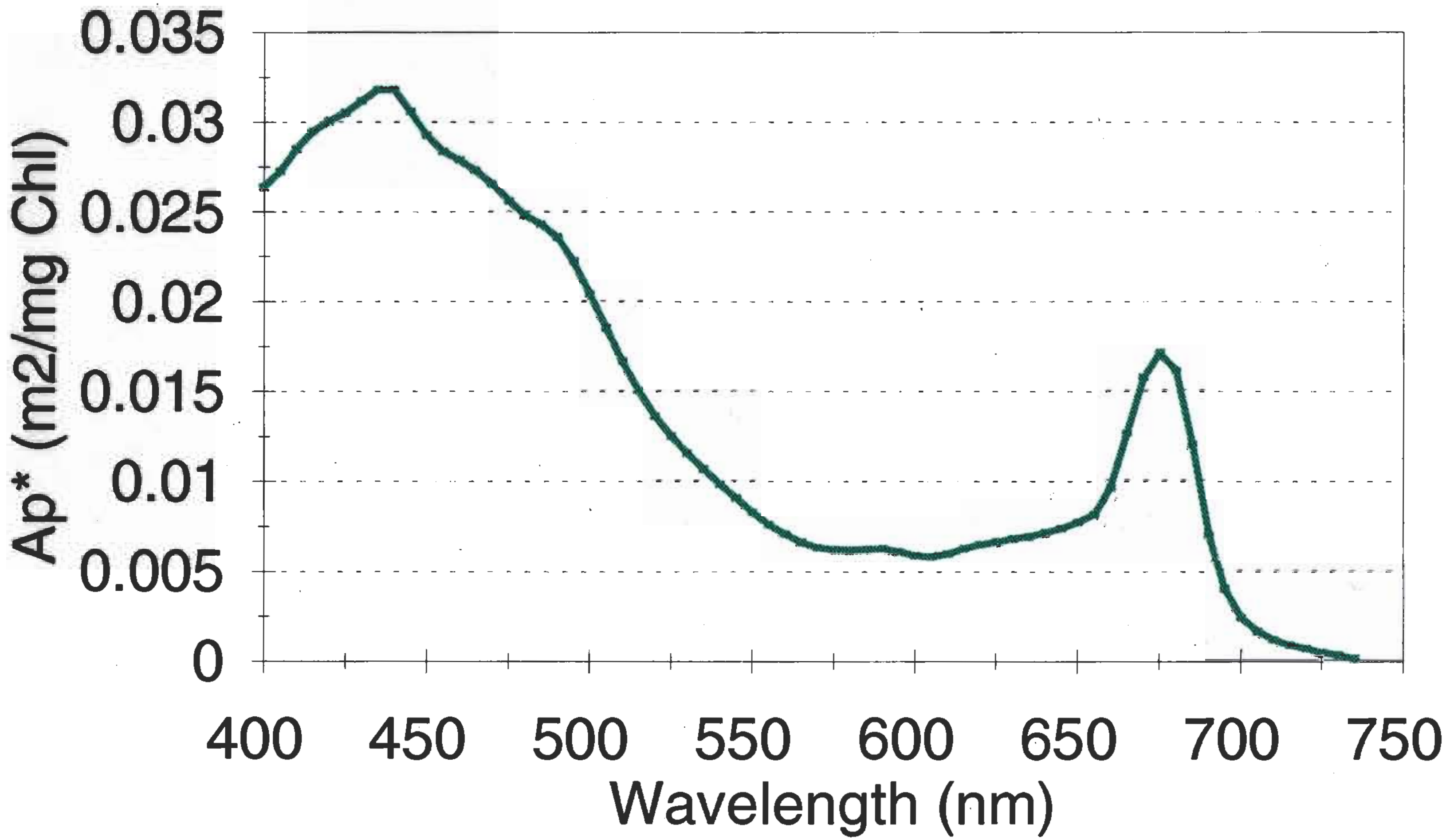


Fig. 2. This figure depicts the lineages supporting key metabolisms of the sulfur cycle, as well as other important metabolisms with relevance for the cycling of sulfur. The Archaeal and Bacterial Domains are represented here, while the Domain Eucarya is not shown. See figure 1 as a reference for the lineages depicted.

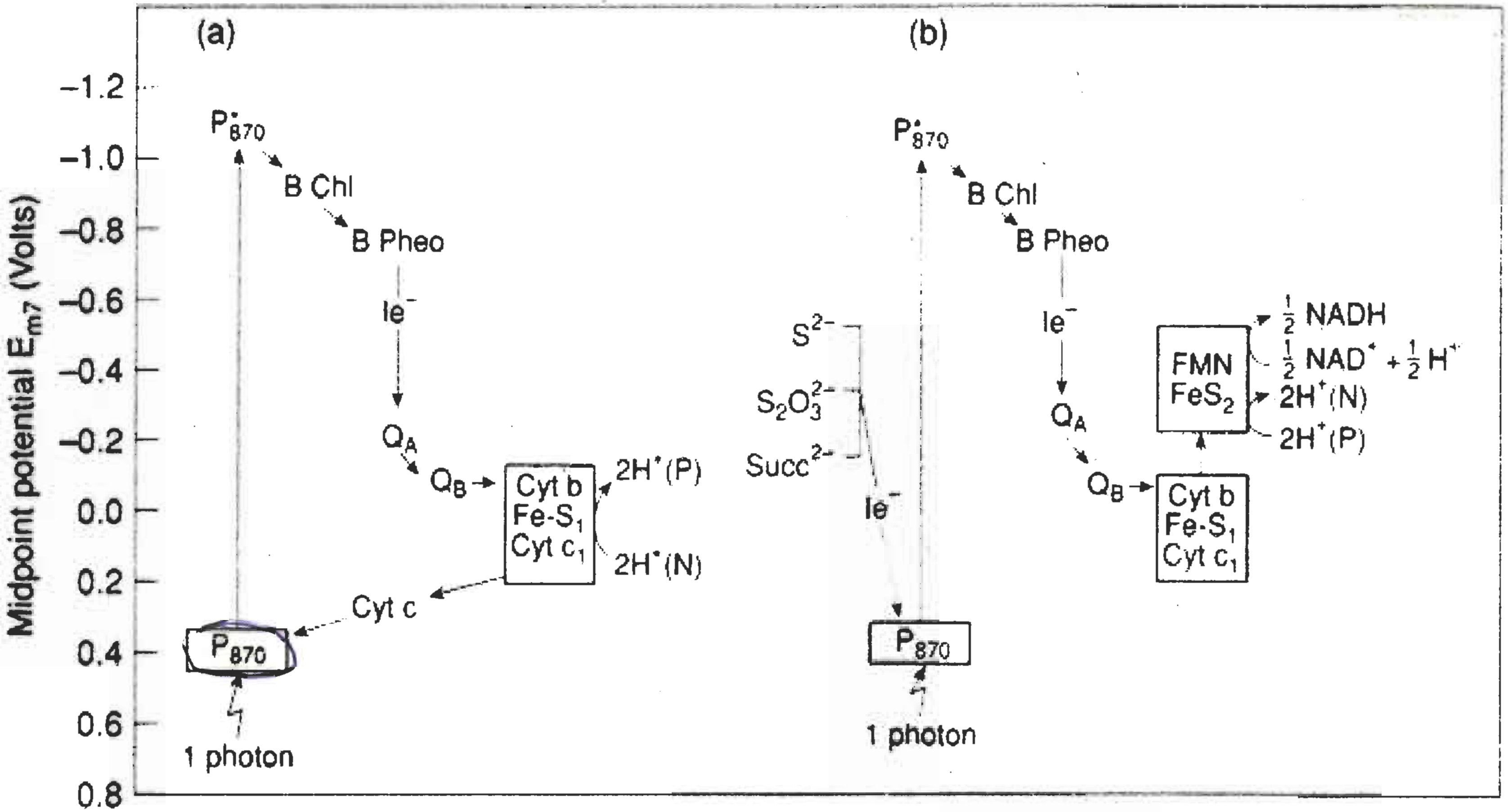
Anabaena sp.



Phytoplankton Absorption



Electron Transport in Photosynthetic Bacteria



From: Falkowski & Raven. Aquatic Photosynthesis. (1997)