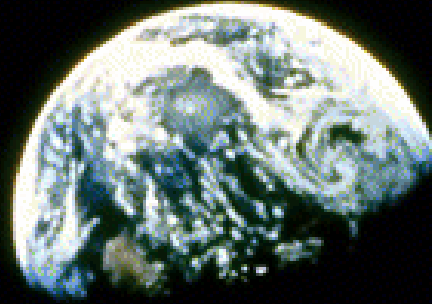




Light and photosynthesis

spectrum/photon types

absorption spectra and emission spectra (fluorescence)

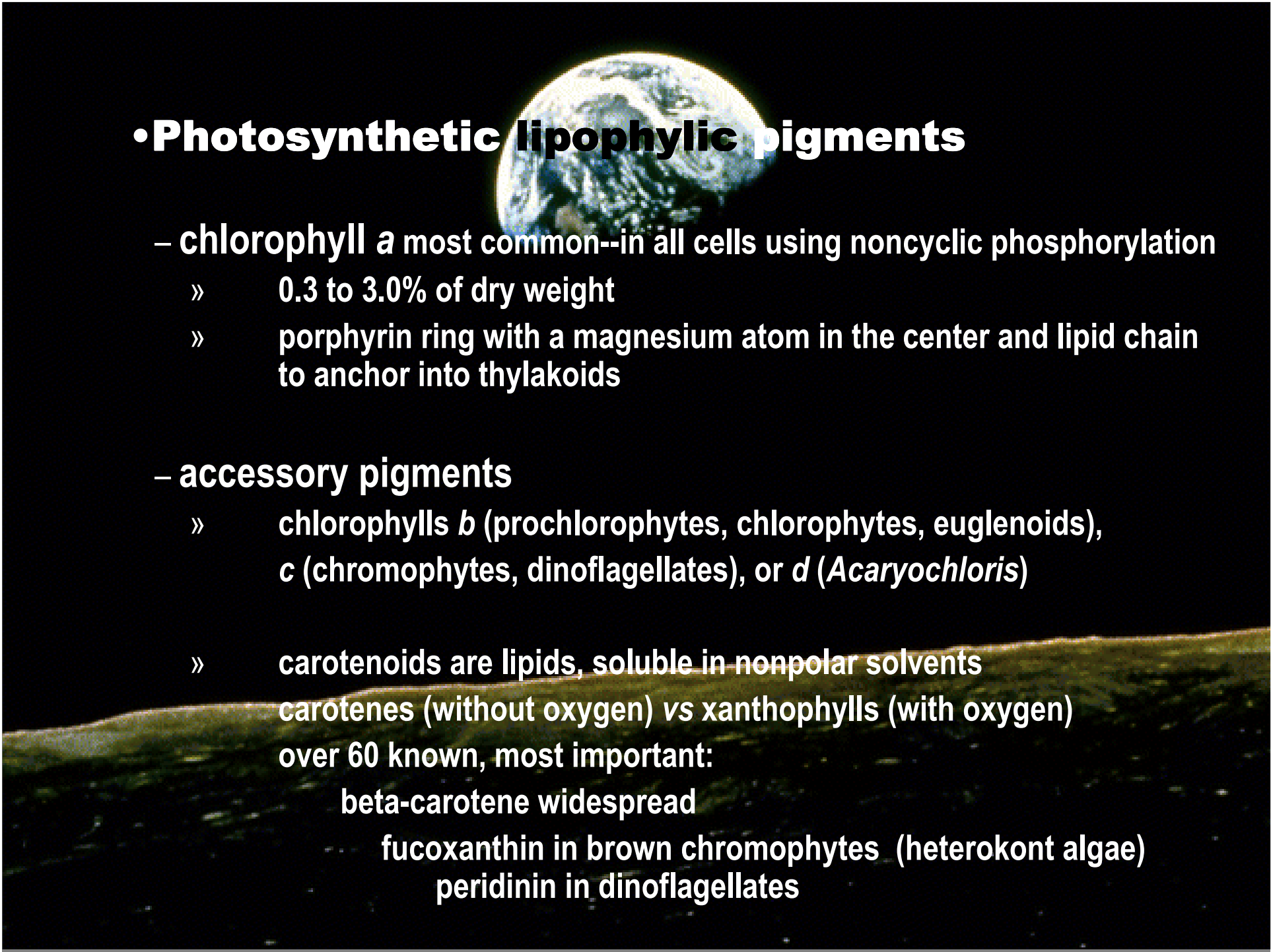
action spectrum = photosynthetically active region of the spectrum

units of measurement

Photosynthesis measurement

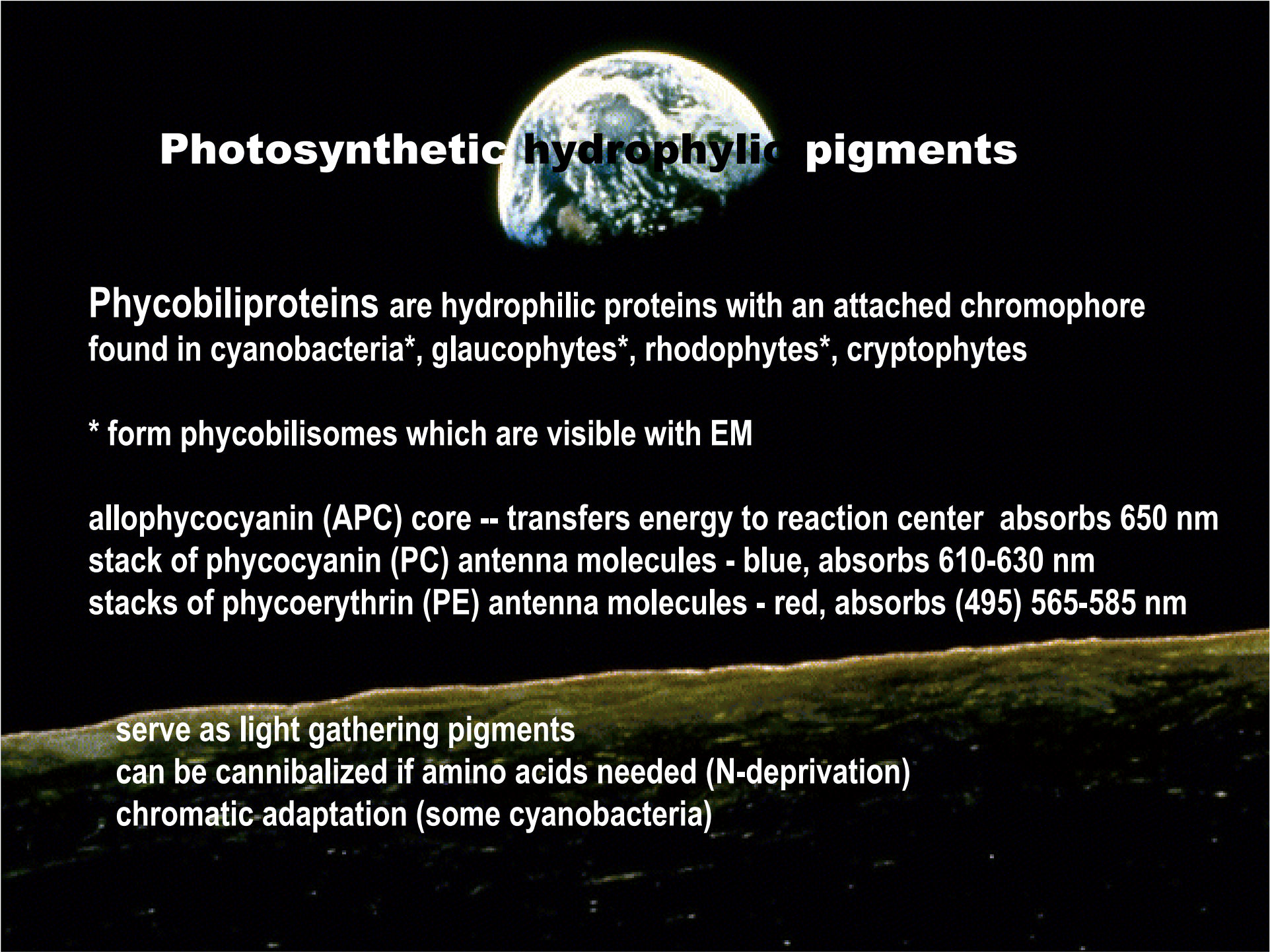
P/I curves

Light acclimation



• **Photosynthetic lipophylic pigments**

- **chlorophyll *a*** most common--in all cells using noncyclic phosphorylation
 - » 0.3 to 3.0% of dry weight
 - » porphyrin ring with a magnesium atom in the center and lipid chain to anchor into thylakoids
- **accessory pigments**
 - » chlorophylls *b* (prochlorophytes, chlorophytes, euglenoids), *c* (chromophytes, dinoflagellates), or *d* (*Acaryochloris*)
 - » carotenoids are lipids, soluble in nonpolar solvents
carotenes (without oxygen) vs xanthophylls (with oxygen)
over 60 known, most important:
 - beta-carotene widespread
 - fucoxanthin in brown chromophytes (heterokont algae)
 - peridinin in dinoflagellates



Photosynthetic hydrophylic pigments

Phycobiliproteins are hydrophilic proteins with an attached chromophore found in cyanobacteria*, glaucophytes*, rhodophytes*, cryptophytes

* form phycobilisomes which are visible with EM

allophycocyanin (APC) core -- transfers energy to reaction center absorbs 650 nm

stack of phycocyanin (PC) antenna molecules - blue, absorbs 610-630 nm

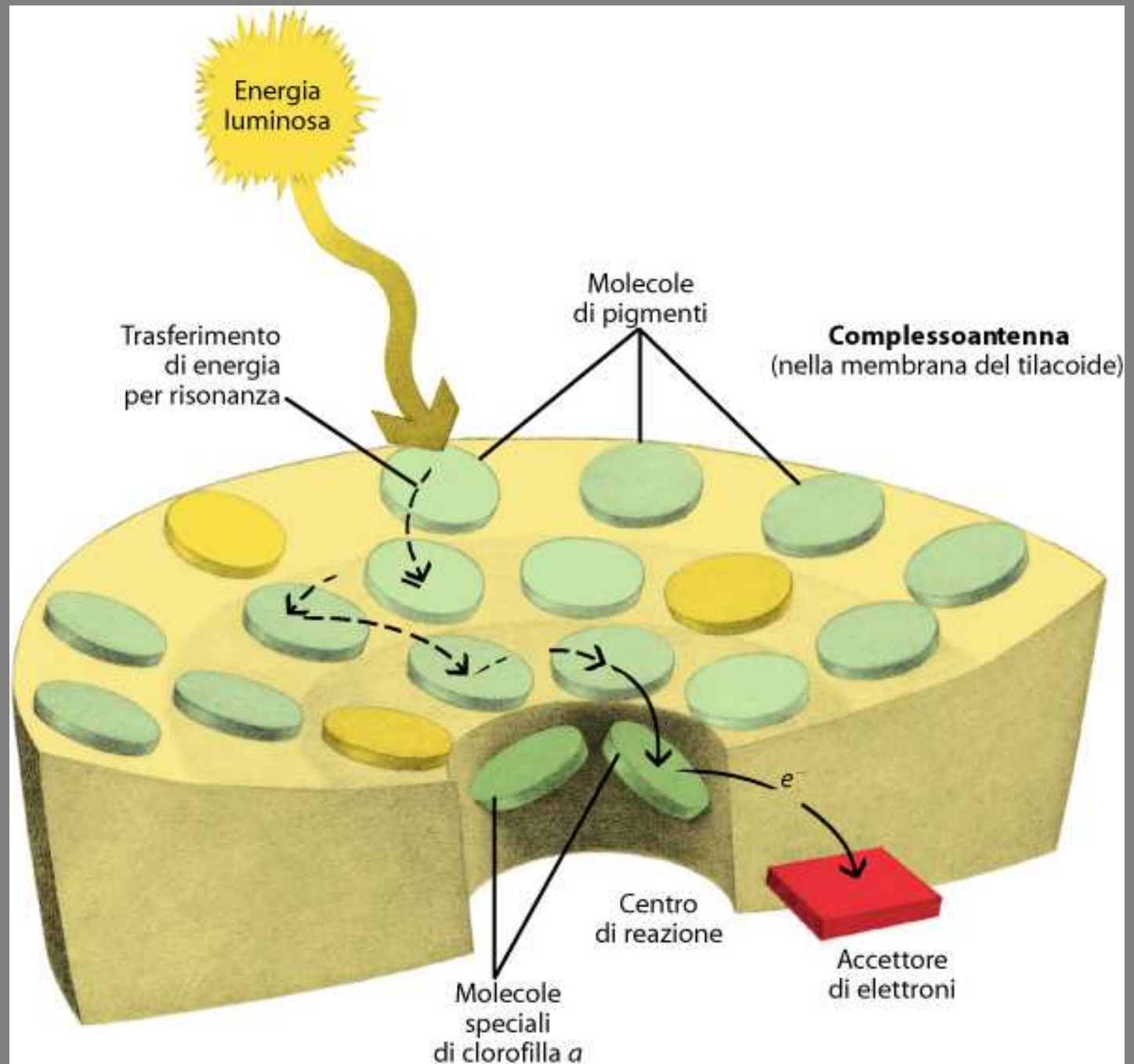
stacks of phycoerythrin (PE) antenna molecules - red, absorbs (495) 565-585 nm

serve as light gathering pigments

can be cannibalized if amino acids needed (N-deprivation)

chromatic adaptation (some cyanobacteria)

FOTOSINTESI E RUOLO DEI PIGMENTI FOTOSINTETICI



Photosynthetic structures

- **thylakoids and other photosynthetic membranes**
 - **contain the photosynthetic pigments and electron transport chains**
 - **usually not arranged in the grana of higher plants; instead there are single or bands of thylakoids, usually containing three to five thylakoids per band; sometimes an additional thylakoid (the girdle lamella) is found under the chloroplast envelope**

Table 1. Major characteristics of the algal groups and cyanobacteria

Phylum	Chl /PBP	Major Carotenoid	Plastid	Stored food	Cell wall	Flagellar type
Haptophytes	a+c ₁ +c ₂	fucoxanthin	3, 4 OMs	c' laminarin	cellulose, alginate	2 equal, smooth
Phaeophytes	a+c ₁ +c ₂	fucoxanthin	3, 4 OMs	laminarin	cellulose, alginate	1-2, unequal, hairy
Bacillariophytes	a+c ₁ +c ₂	fucoxanthin	3, 4 OMs	laminarin	silica, alginate	Male only: 1 hairy
Chrysophytes	a+c ₁ +c ₂	fucoxanthin	3, 4 OMs	c' laminarin	cellulose, silica	1-2, unequal, hairy
Eustigmatophytes	a	violaxanthin	3, 4 OMs	c' laminarin	cellulose,	1-2, unequal, 1 hairy
Xanthophytes	a+c ₁ +c ₂	heteroxanthin	3, 4 OMs	c' laminarin	cellulose	1-2, unequal, 1 hairy
Dinoflagellates	a+c ₂	peridinin	3, 3 OMs	starch, lipid	cellulose, theca	2, unequal, 1 hairy
Cryptophytes	a+c ₂ +PBP	alloxanthin	2, 4 OMs	starch	(protein)	2+/- equal, hairy
Chlorarachniophytes	a+b	violaxanthin	2-6, 4 OMs	starch	cellulose	lacking
Euglenophytes	a+b	diadinoxanthin	3, 3 OMs	paramylon	(protein)	2-several, hairy
Apicomplexans	none	none	none, 4 OMs	?	none	none
Prasinophytes	a+b (c-like)	violaxanthin	2-6, 2 OMs	starch	cellulose	4, scaly smooth or hairy
Chlorophytes	a+b	siphonaxanthin	2-6, 2 OMs	starch	cellulose	2(4), equal, smooth
Charophytes	a+b	zeaxanthin	many, 2 OMs	starch	cellulose	2 equal hairy or scaly
Glaucocystophytes	a+PBP	lutein	0, 2 Oms +pepidoglycan wall	starch	cellulose/xylan	lacking
Rhodophytes	a+PBP	lutein	0, 2 OMs	flor. starch	cellulose/xylan	lacking
Cyanobacteria	a+PBP	echinenone	none	glycogen	murein	lacking
Cyanobacteria (prochlorophytes)	a+b±c-like ±PBP	echinenone	none		murein	lacking
Cyanobacteria (<i>Acaryochloris</i>)	a+d +PBP	echinenone	none	glycogen	murein	lacking

Flor. starch, floridean starch; glycogen = cyanophycean starch; PBP, phycobiliprotein; OM, plastid envelope membranes; c' laminarin. chrysolaminarin. Plastid: the first number refers to the typical number of stacked thylakoids; the second number refers to the number of outer membranes (OM).

Photosynthetic plastid structure

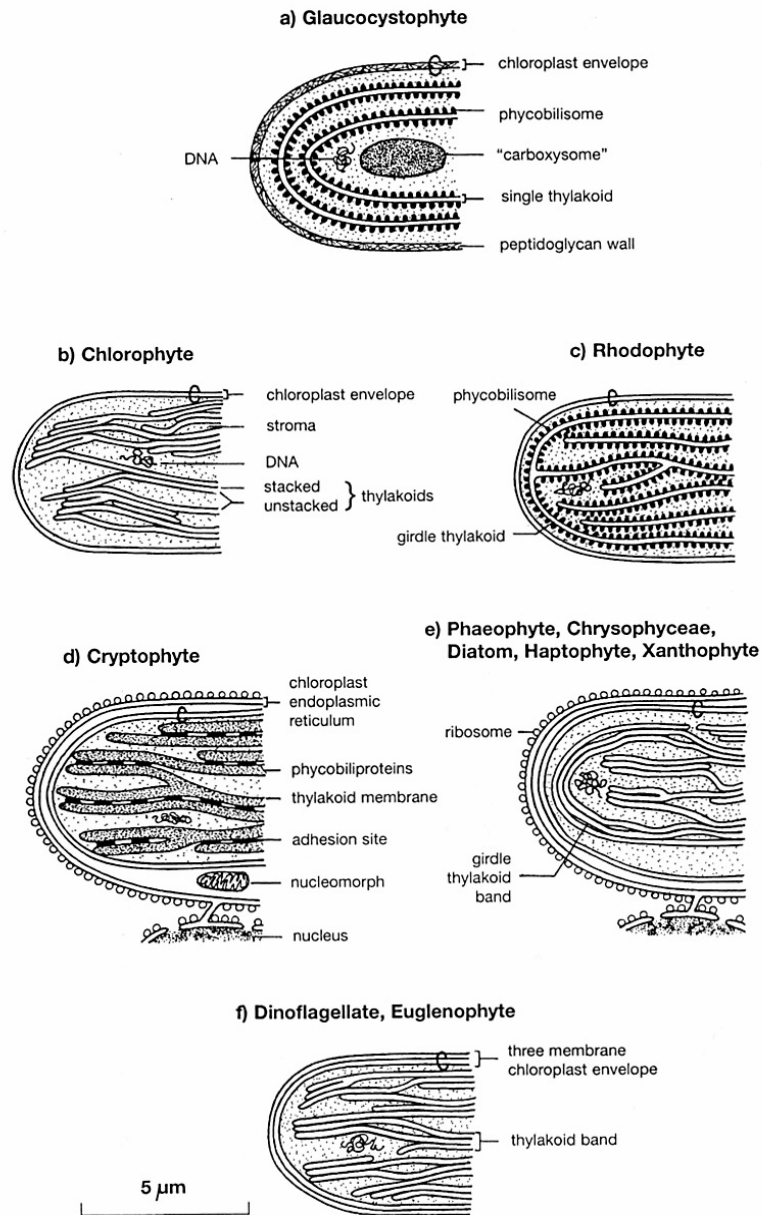
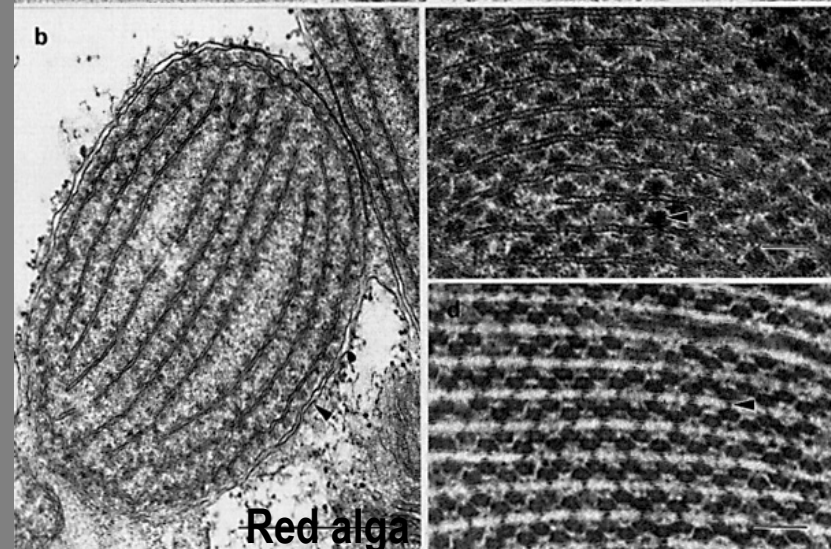
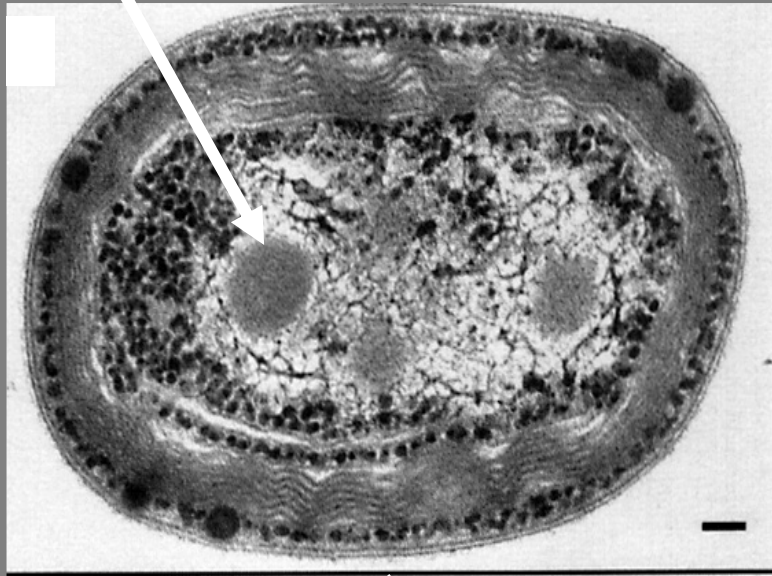


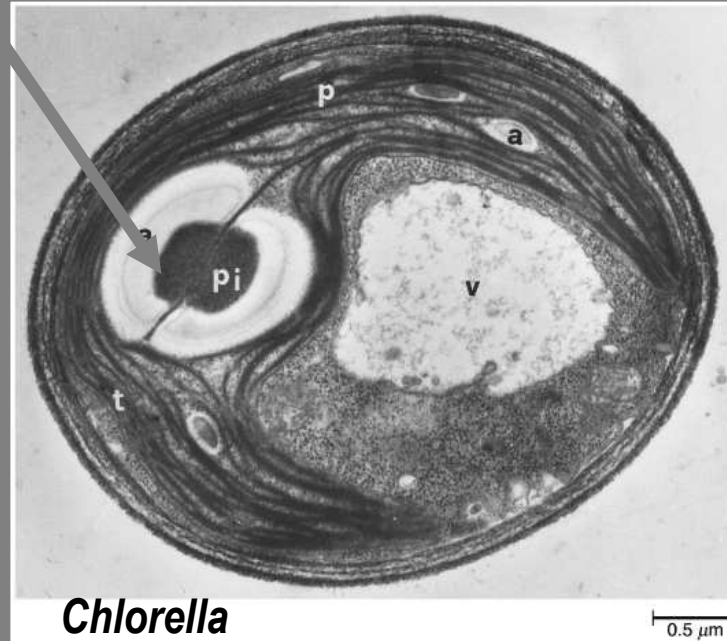
Fig. 1. Diagrams to show the typical arrangement of plastid envelopes and thylakoids in a) glaucocystophytes; b) chlorophytes; c) rhodophytes; d) cryptophytes; e) chrysophytes, phaeophytes, diatoms, xanthophytes, haptophytes, etc and f) dinoflagellates and euglenophytes.



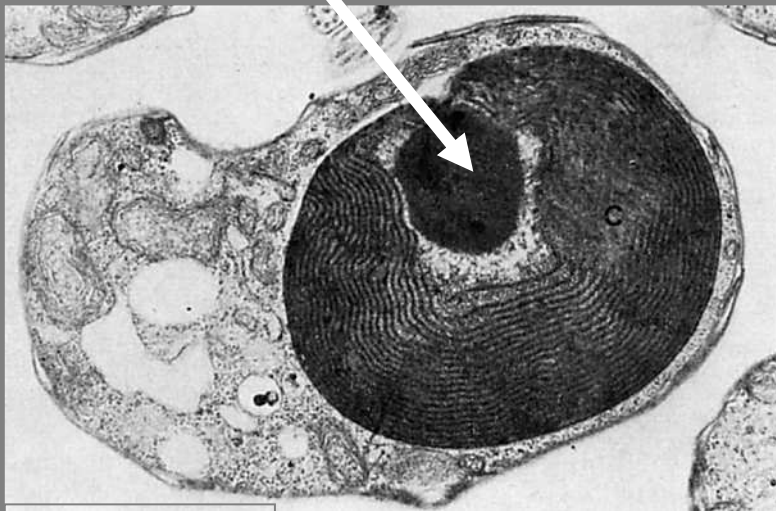
Carboxysomes and pyrenoids



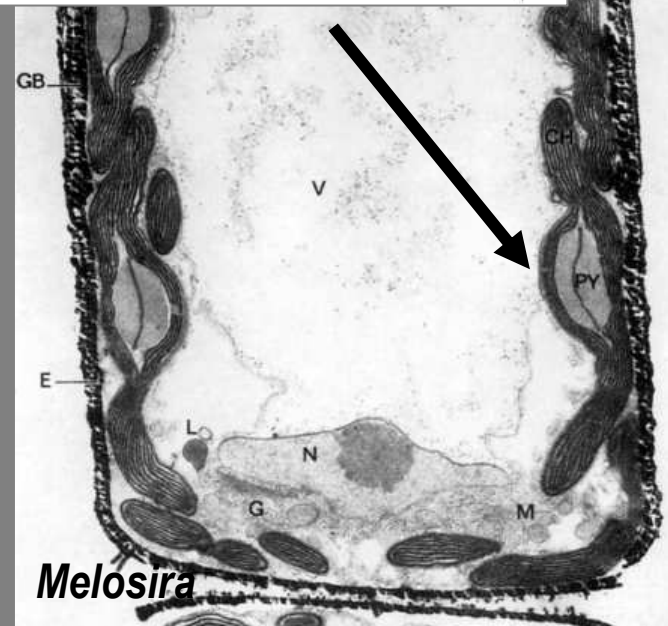
Akaryochloris



Chlorella



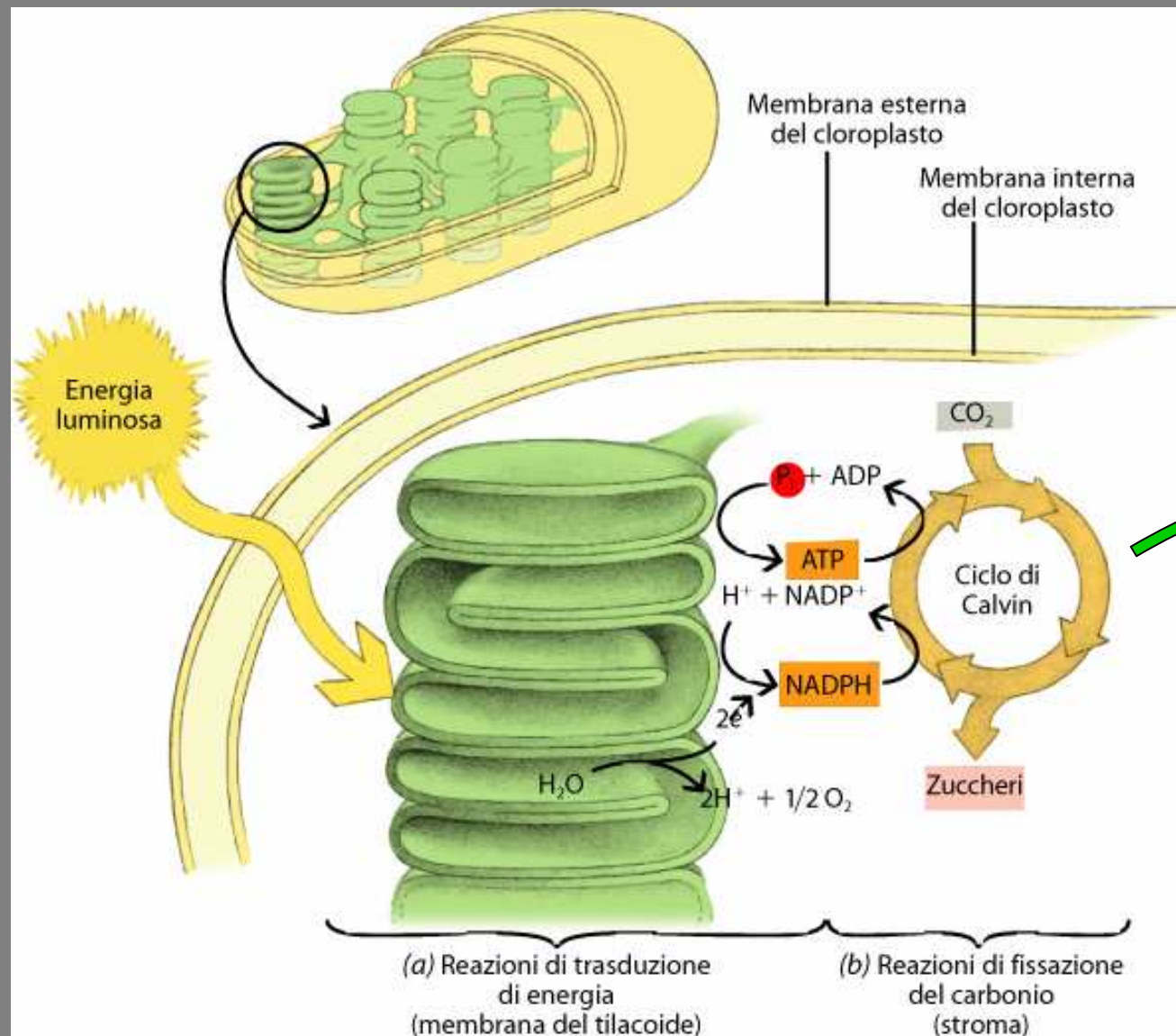
Cyanophora



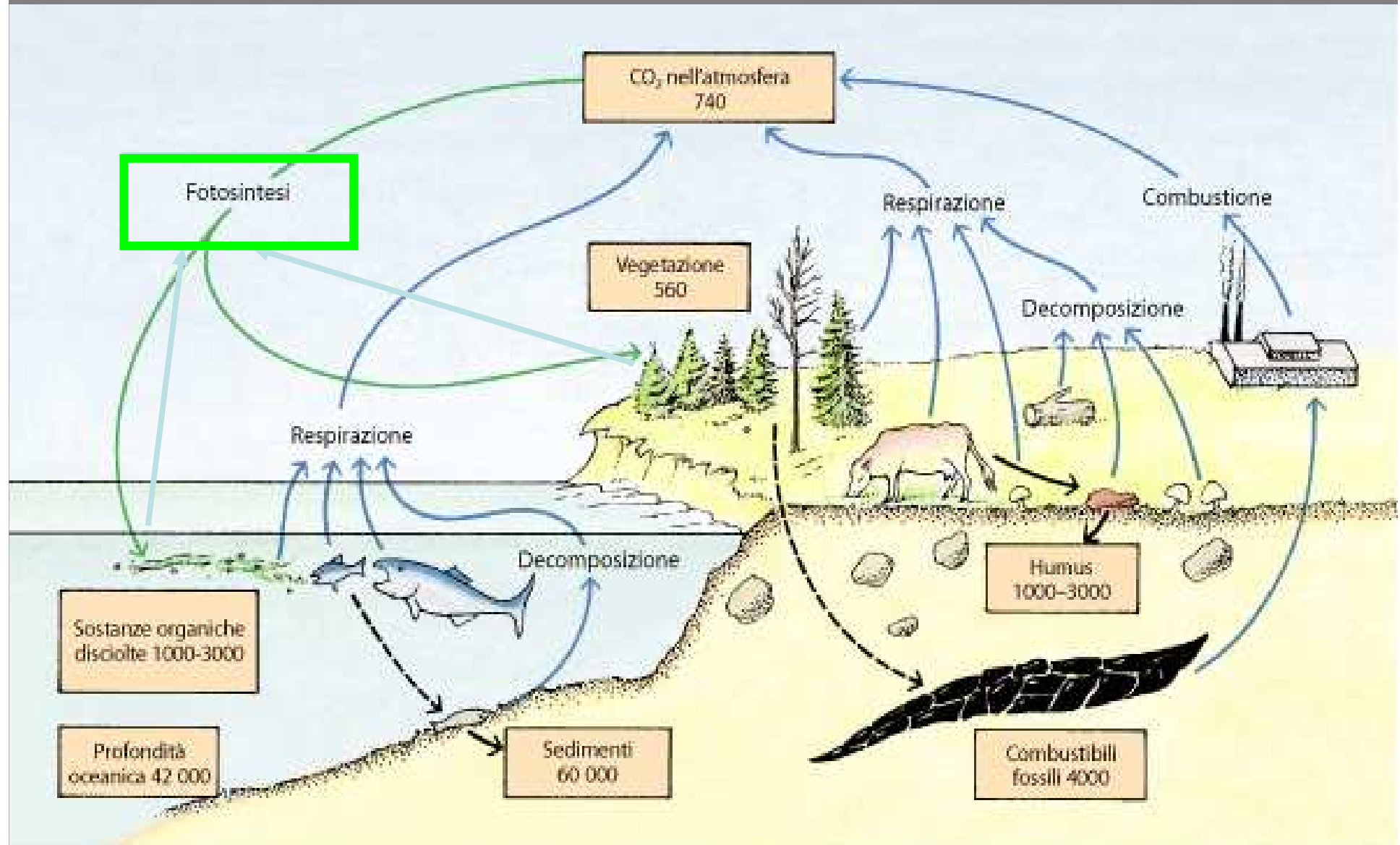
Melosira

Photosynthetic structures

- thylakoids and other photosynthetic membranes
 - usually not arranged in the grana of higher plants , only few green algae
 - single thylakoids in Cyanobacteria, Glaucophyta, Rhodophyta
 - bands of thylakoids, usually containing two to six thylakoids in Chlorophytes
 - three per lamella in other algae, sometimes additional girdle lamella is found under the chloroplast envelope
- pyrenoids
 - in stroma
 - RuBP carboxylase in some sort of package, may be with carbonic anhydrase
 - sometimes penetrated by thylakoids



Ciclo del Carbonio



* Numeri in box = miliardi di tonnellate

CO_2 in air = 12-15 μM (0.036% but 10^4 higher diffusion than in water)

CO_2 in seawater = 10 μM

HCO_3^- in seawater = 2 mM (90%) } pH 8.0, salinity 35 ‰

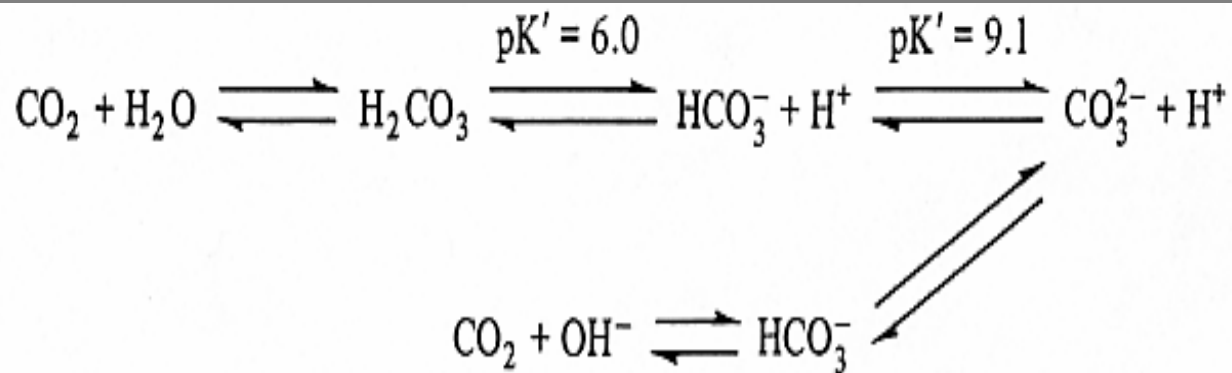
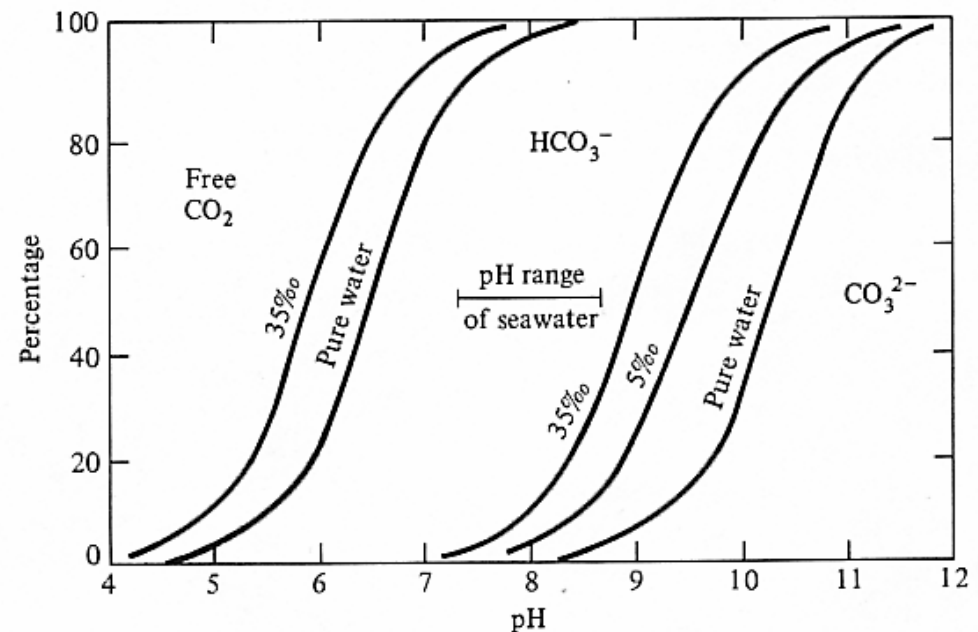
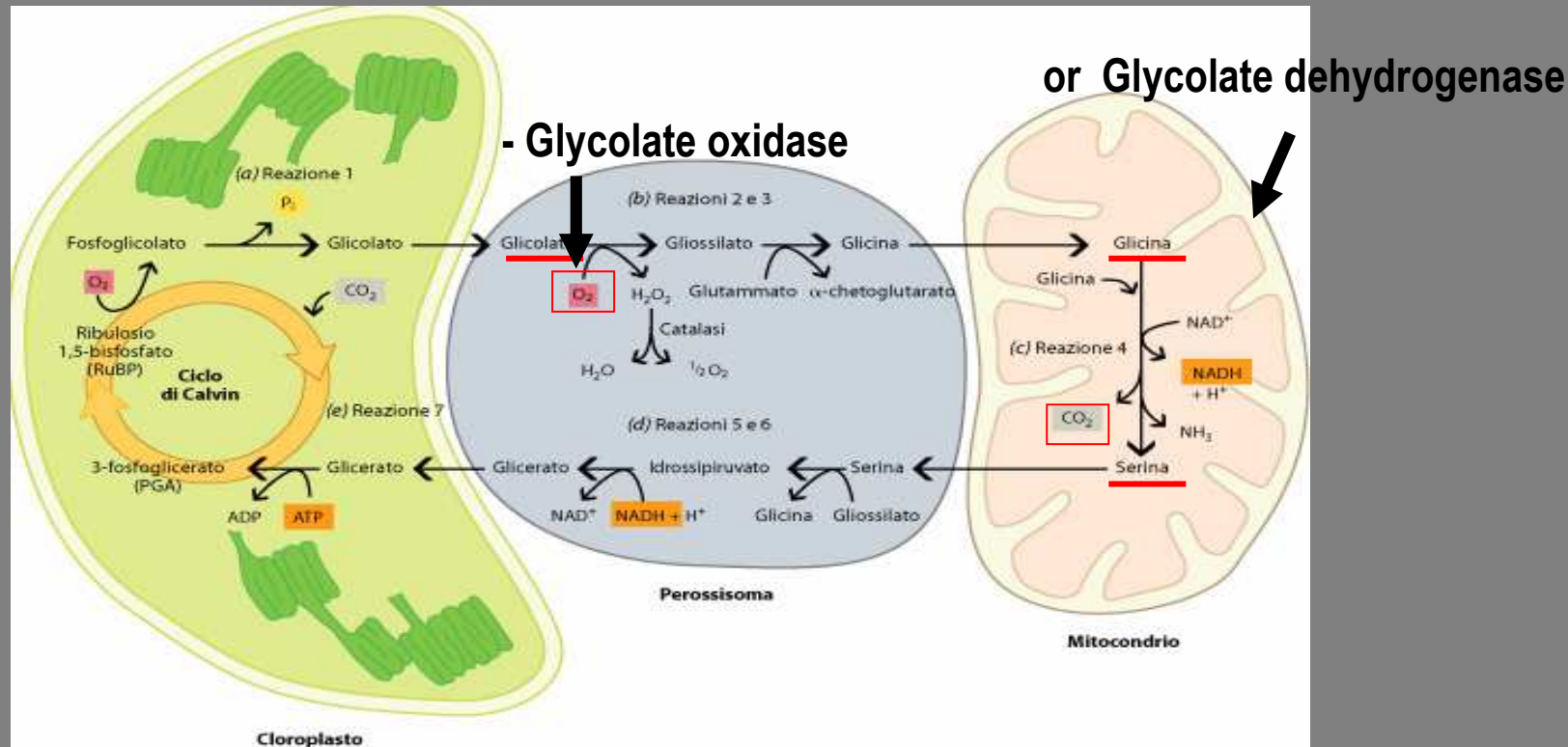


Figure 4.16. The carbonate equilibrium.

Figure 4.17. Percentage distribution of different forms of inorganic carbon in seawater as a function of pH in three different salinities.





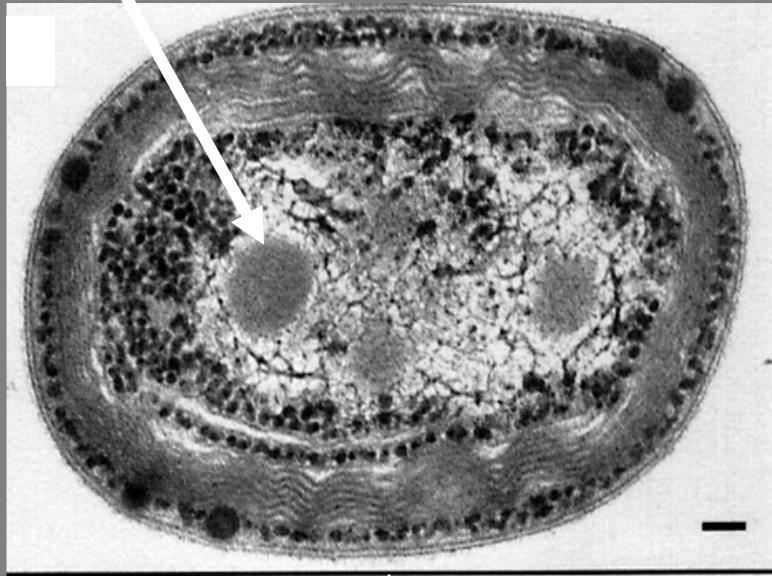
- Rubisco with higher CO_2 affinity (K_m 80-330 $\rightarrow$ 45-70, up to 10-25 mmol)

- Carbon-Concentration Mechanisms (CCMs):

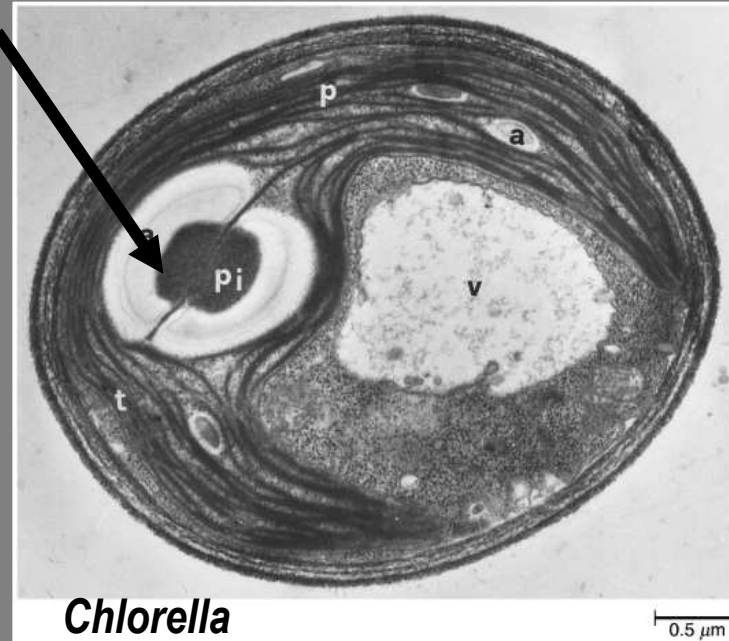


{ periplasm
carboxysomes
pyrenoids

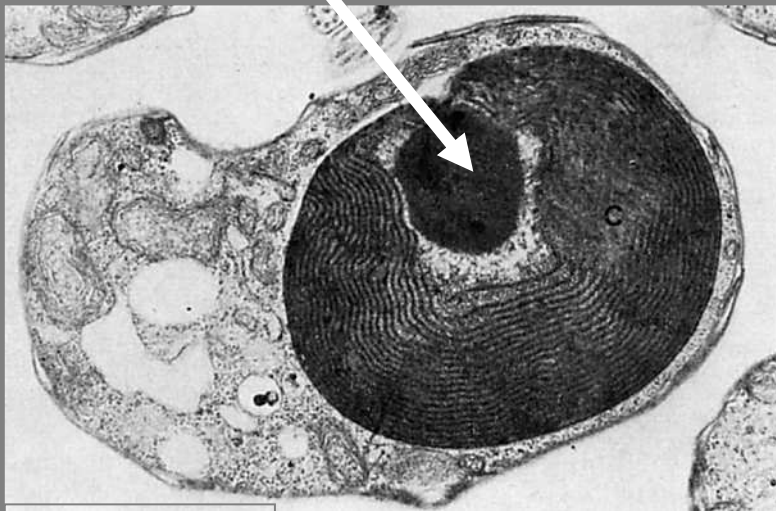
Carboxysomes and pyrenoids: Rubisco + Carbonic Anhydrase (CA)



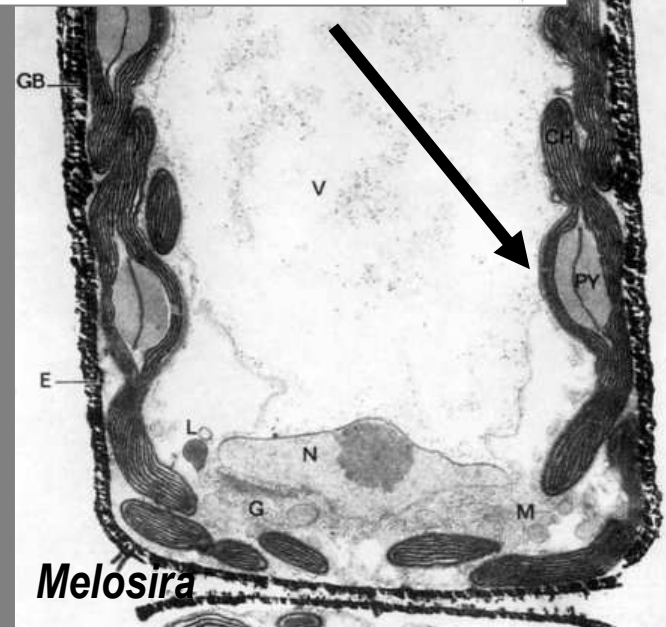
Akaryochloris



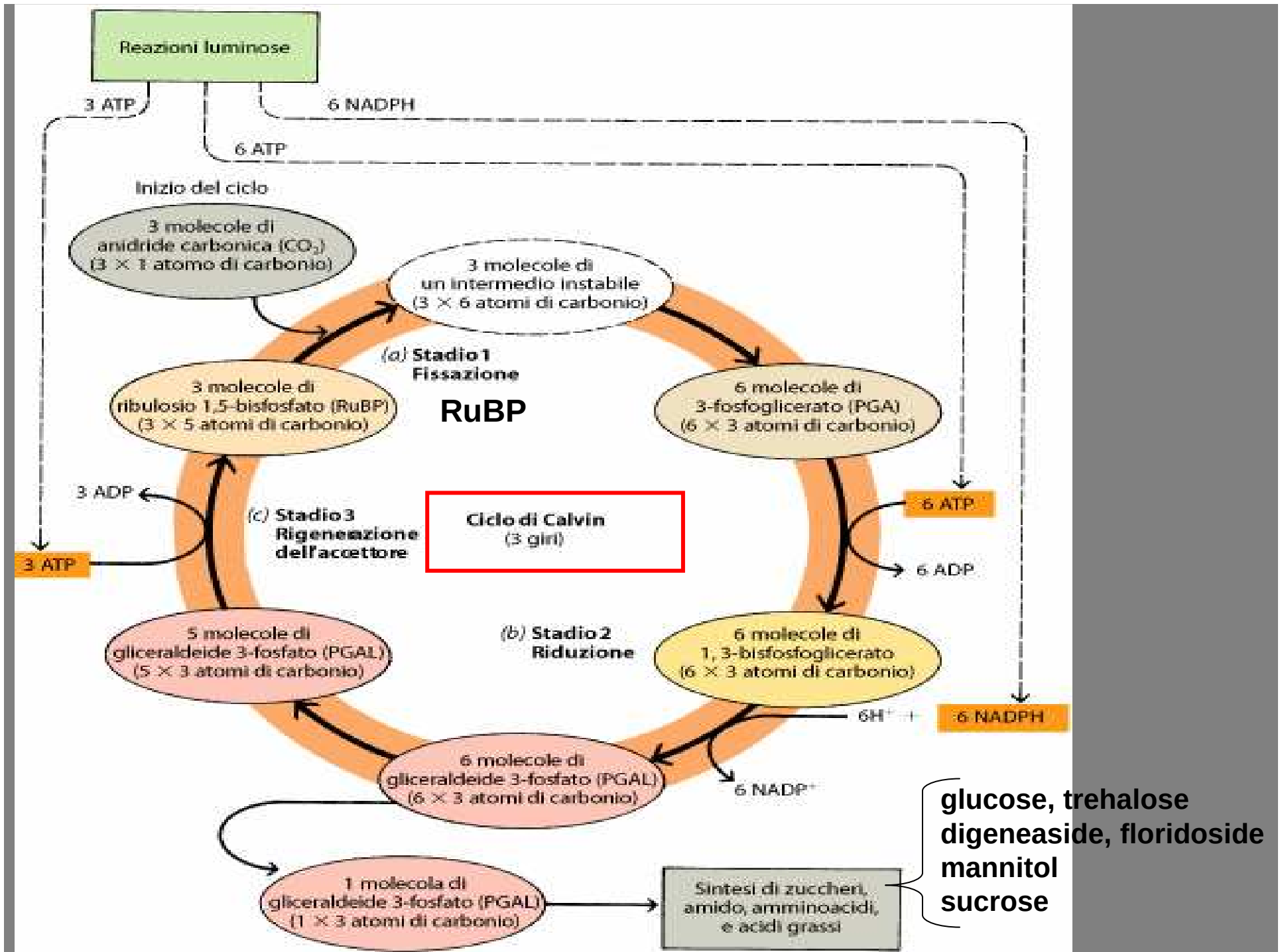
Chlorella



Cyanophora



Melosira

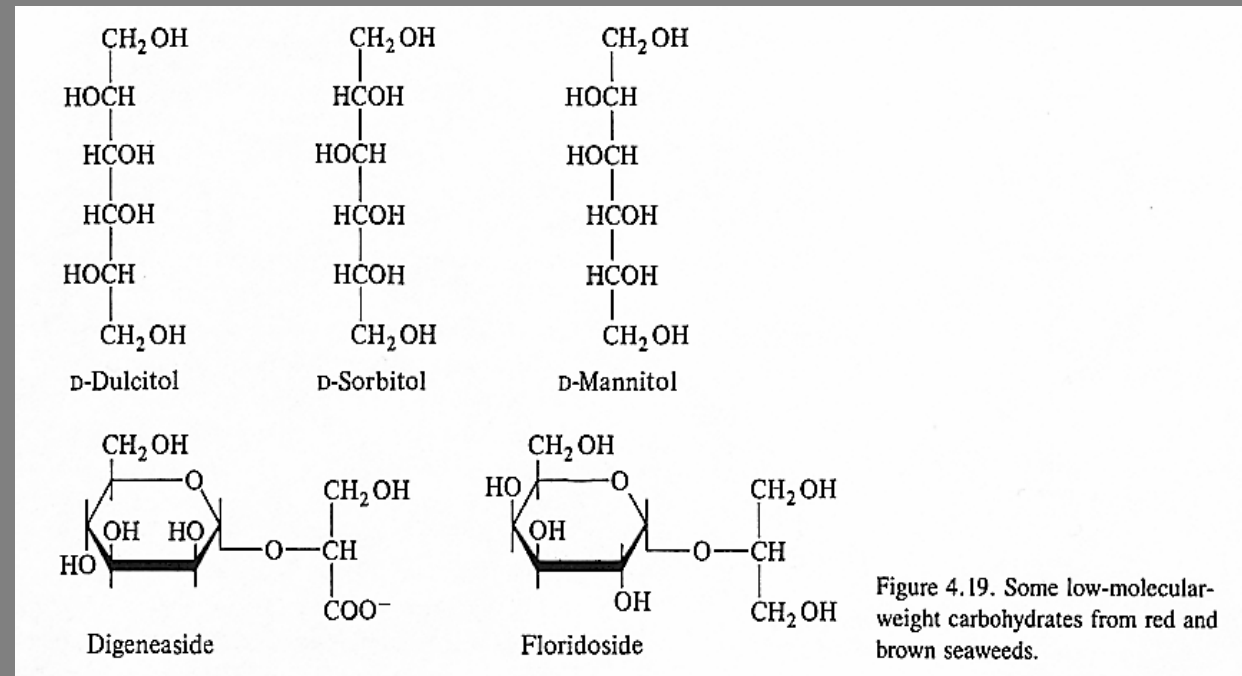


LOW MOLECULAR WEIGHT PHOTOSYNTHATES

glucose
trehalose
digeneaside
floridoside
mannitol
sucrose



translocation
synthesis
osmolites



HIGH MOLECULAR WEIGHT PHOTOSYNTHATES

- A) storage polymers
- B) wall-matrix polysaccharides (PS)

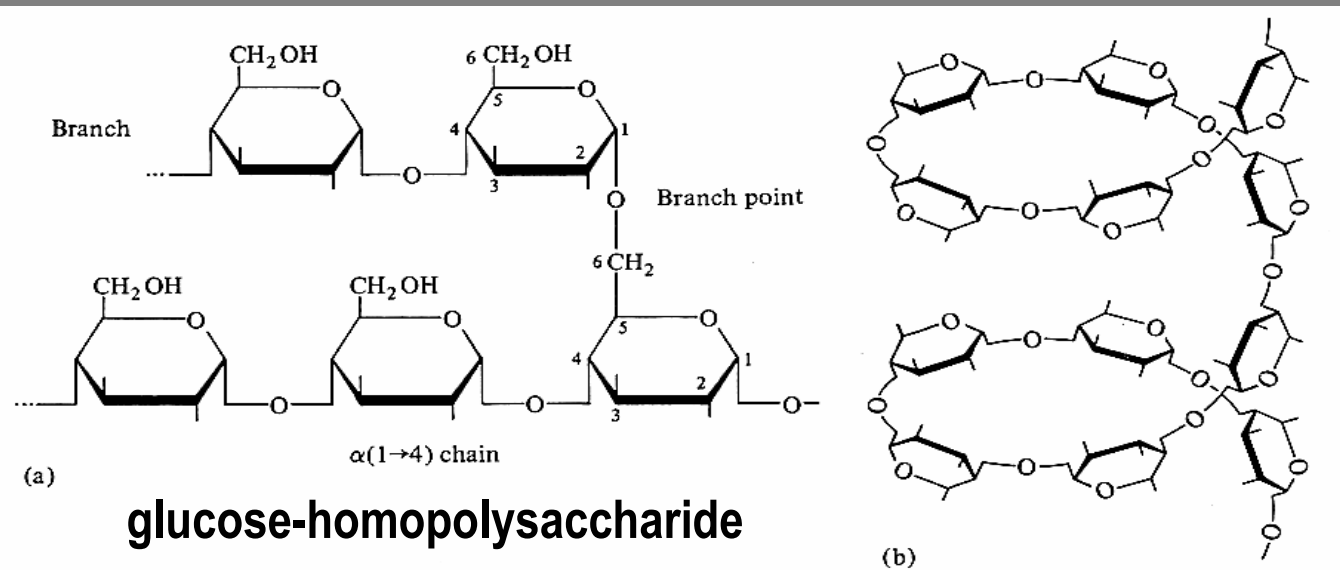
Table 1. Major characteristics of the algal groups and cyanobacteria

Phylum	Chl /PBP	Major Carotenoid	Plastid	Stored food	Cell wall	Flagellar type
Haptophytes	a+c ₁ +c ₂	fucoxanthin	3, 4 OMs	c'laminarin	cellulose, alginate	2 equal, smooth
Phaeophytes	a+c ₁ +c ₂	fucoxanthin	3, 4 OMs	laminarin	cellulose, alginate	1-2,unequal,hairy
Bacillariophytes	a+c ₁ +c ₂	fucoxanthin	3, 4 OMs	laminarin	silica, alginate	Male only: 1 hairy
Chrysophytes	a+c ₁ +c ₂	fucoxanthin	3, 4 OMs	c'laminarin	cellulose, silica	1-2,unequal,hairy
Eustigmatophytes	a	violaxanthin	3, 4 OMs	c'laminarin	cellulose,	1-2,unequal,1 hairy
Xanthophytes	a+c ₁ +c ₂	heteroxanthin	3, 4 OMs	c'laminarin	cellulose	1-2,unequal,1 hairy
Dinoflagellates	a+c ₂	peridinin	3, 3 OMs	starch, lipid	cellulose, theca	2,unequal,1 hairy
Cryptophytes	a+c ₂ +PBP	alloxanthin	2, 4 OMs	starch	(protein)	2+/- equal, hairy
Chlorarachniophytes	a+b	violaxanthin	2-6, 4OMs	starch	cellulose	lacking
Euglenophytes	a+b	diadinoxanthin	3, 3 OMs	paramylon	(protein)	2-several,hairy
Apicomplexans	none	none	none, 4 OMs	?	none	none
Prasinophytes	a+b (c-like)	violaxanthin	2-6, 2 OMs	starch	cellulose	4, scaly smooth or hairy
Chlorophytes	a+b	siphonaxanthin	2-6, 2 OMs	starch	cellulose	2(4),equal, smooth
Charophytes	a+b	zeaxanthin	many, 2 OMs	starch	cellulose	2 equal hairy or scaly
Glaucocystophytes	a+PBP	lutein	0, 2 Oms +pepidoglycan wall	starch	cellulose/xylan	lacking
Rhodophytes	a+PBP	lutein	0, 2 OMs	flor. starch	cellulose/xylan	lacking
Cyanobacteria	a+PBP	echinenone	none	glycogen	murein	lacking
Cyanobacteria (prochlorophytes)	a+b±c-like ±PBP	echinenone	none		murein	lacking
Cyanobacteria (<i>Acaryochloris</i>)	a+d +PBP	echinenone	none	glycogen	murein	lacking

Flor. starch, floridean starch; myx. starch, cyanophycean starch; PBP, phycobiliprotein; OM, plastid envelope membranes; c'laminarin, chrysolaminarin. Plastid: the first number refers to the typical number of stacked thylakoids; the second number refers to the number of outer membranes (OM).

Storage polymers of algae

Starch



laminaran

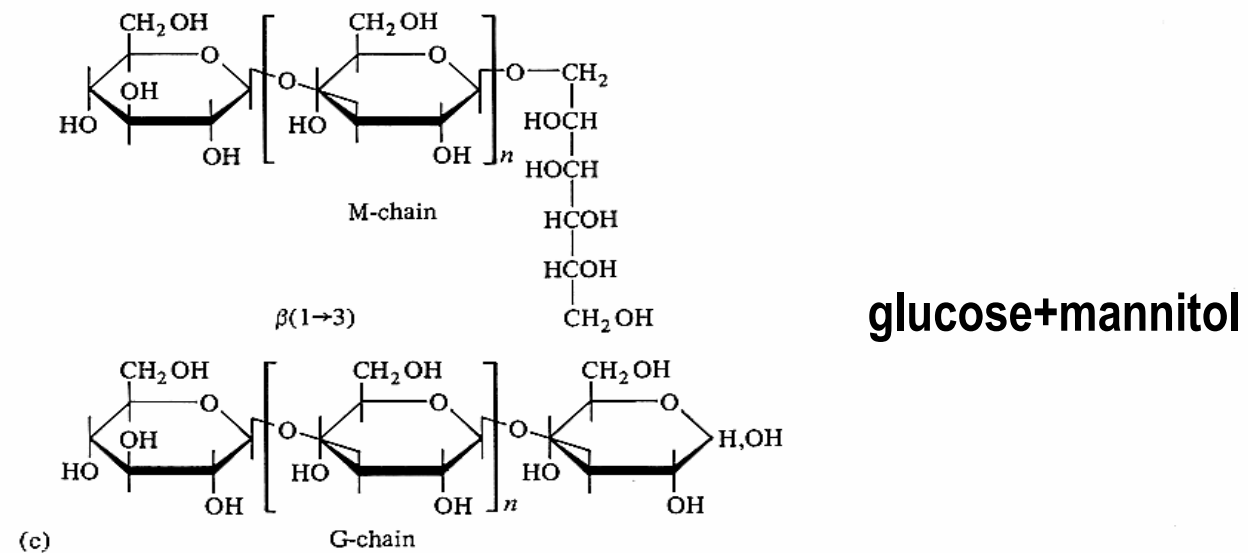


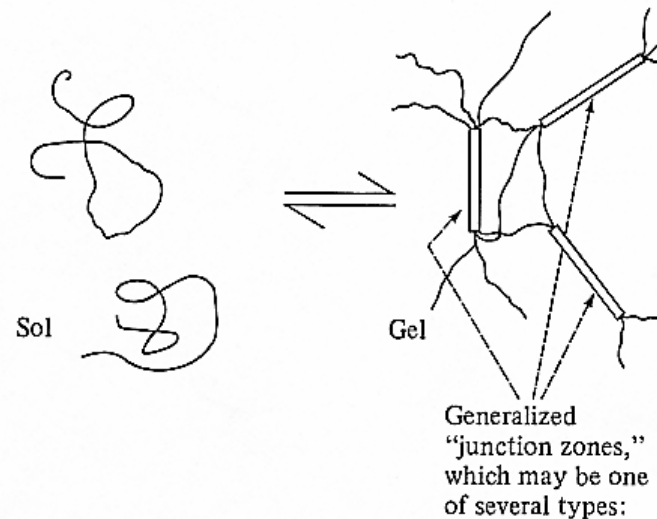
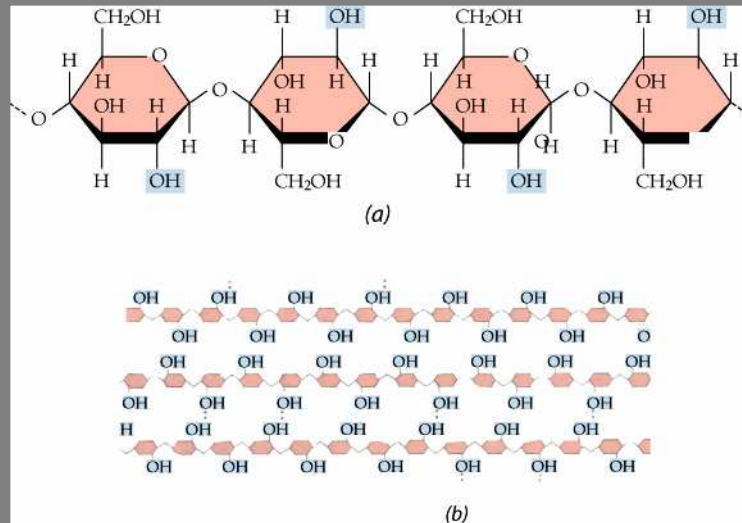
Figure 4.21. Algal storage polysaccharides: (a) amylopectin; (b) amylose; (c) two types of laminaran chains, M with mannitol attached to the reducing end, G with glucose at the reducing end.

Table 1. Major characteristics of the algal groups and cyanobacteria

Phylum	Chl /PBP	Major Carotenoid	Plastid	Stored food	Cell wall	Flagellar type
Haptophytes	$a+c_1+c_2$	fucoxanthin	3, 4 OMs	c'laminarin	cellulose, alginate	2 equal, smooth
Phaeophytes	$a+c_1+c_2$	fucoxanthin	3, 4 OMs	laminarin	cellulose, alginate	1-2,unequal,hairy
Bacillariophytes	$a+c_1+c_2$	fucoxanthin	3, 4 OMs	laminarin	silica, alginate	Male only: 1 hairy
Chrysophytes	$a+c_1+c_2$	fucoxanthin	3, 4 OMs	c'laminarin	cellulose, silica	1-2,unequal,hairy
Eustigmatophytes	a	violaxanthin	3, 4 OMs	c'laminarin	cellulose,	1-2,unequal,1 hairy
Xanthophytes	$a+c_1+c_2$	heteroxanthin	3, 4 OMs	c'laminarin	cellulose	1-2,unequal,1 hairy
Dinoflagellates	$a+c_2$	peridinin	3, 3 OMs	starch, lipid	cellulose, theca	2,unequal,1 hairy
Cryptophytes	$a+c_2$ +PBP	alloxanthin	2, 4 OMs	starch	(protein)	2+/- equal, hairy
Chlorarachniophytes	a+b	violaxanthin	2-6, 4OMs	starch	cellulose	lacking
Euglenophytes	a+b	diadinoxanthin	3, 3 OMs	paramylon	(protein)	2-several,hairy
Apicomplexans	none	none	none, 4 OMs	?	none	none
Prasinophytes	a+b (c-like)	violaxanthin	2-6, 2 OMs	starch	cellulose	4, scaly smooth or hairy
Chlorophytes	a+b	siphonaxanthin	2-6, 2 OMs	starch	cellulose	2(4),equal, smooth
Charophytes	a+b	zeaxanthin	many, 2 OMs	starch	cellulose	2 equal hairy or scaly
Glaucocystophytes	a+PBP	lutein	0, 2 Oms +pepidoglycan wall	starch	cellulose/xylan	lacking
Rhodophytes	a+PBP	lutein	0, 2 OMs	flor. starch	cellulose/xylan	lacking
Cyanobacteria	a+PBP	echinenone	none	glycogen	murein	lacking
Cyanobacteria (prochlorophytes)	$a+b\pm c$ -like $\pm$ PBP	echinenone	none		murein	lacking
Cyanobacteria (<i>Acaryochloris</i>)	a+d +PBP	echinenone	none	glycogen	murein	lacking

Flor. starch, floridean starch; myx. starch, cyanophycean starch; PBP, phycobiliprotein; OM, plastid envelope membranes; c'laminarin, chrysolaminarin. Plastid: the first number refers to the typical number of stacked thylakoids; the second number refers to the number of outer membranes (OM).

Most of the algae, not all, have cellulosic cell walls plus matrix PS



Cellulose
(β 1 $\rightarrow$ 4 polyglucan)

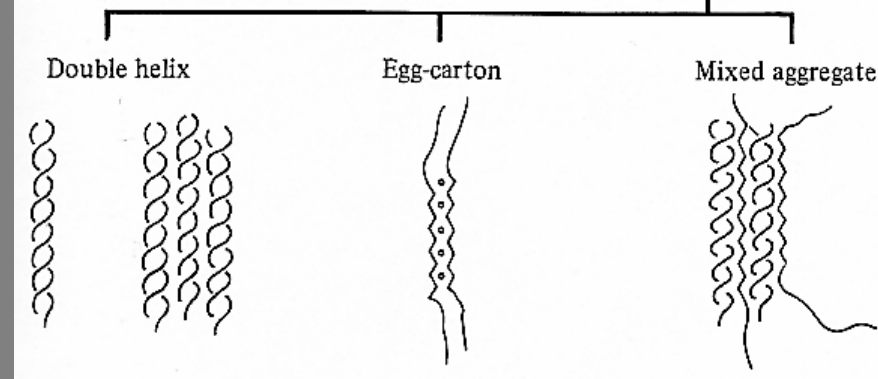
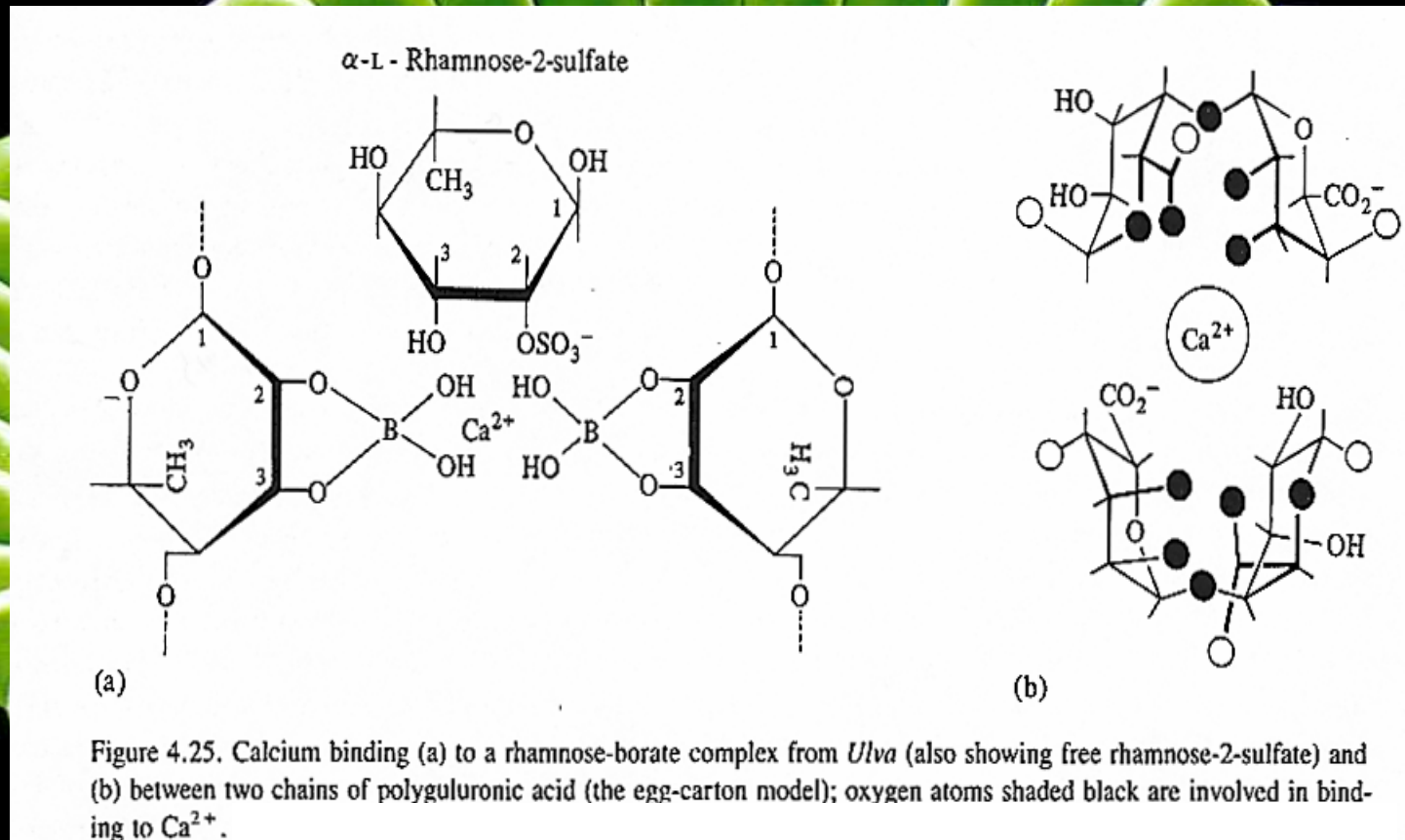


Figure 4.22. Some mechanisms by which a carbohydrate chain may bind to another of similar or different structure with the formation of a gel network. Lower series of drawings, from left to right, correspond to isolated double helix (e.g., ι -carrageenan), aggregated double helices (e.g., agarose), "egg carton" (e.g., calcium polyguluronate), mixed aggregate (e.g., agarose-galactomannan).

+ Wall-matrix polysaccharides



Xylose, rhamnose, etc. - complex heteropolysaccharides

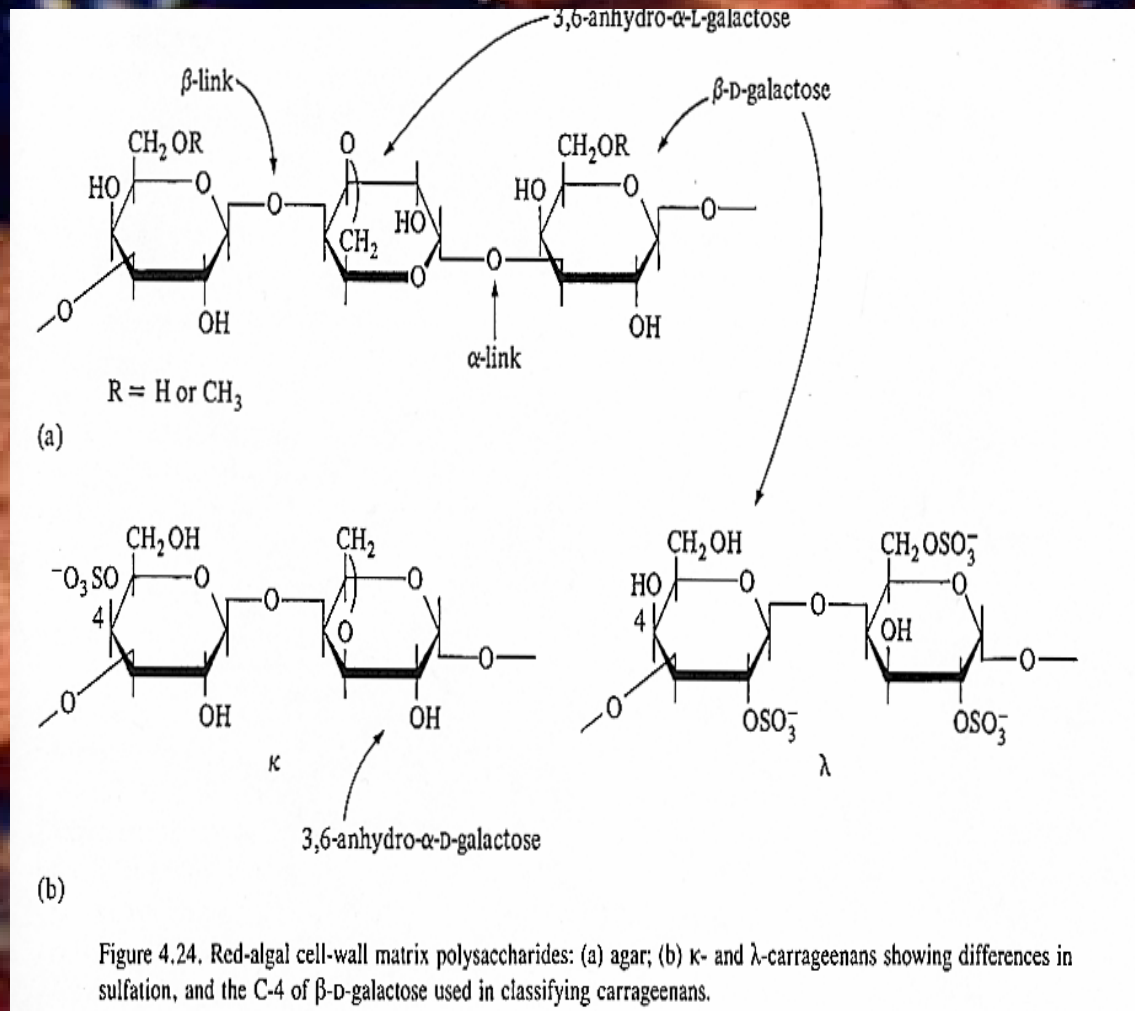
Wall-matrix polysaccharides in green algae

Wall-matrix polysaccharides in red algae

galactose non-sulphated sulphated polysaccharides

agar

carrageenans



[illegible]

Wall-matrix polysaccharide in brown algae

galactose non-sulphated and sulphated polysaccharides

Fucans

(7)

(8)

Fup = L-fucose

Alginate acid

(a)

(b)

(-M-)n

(-G-)n

Figure 4.23. Brown-algal cell-wall matrix polysaccharides: (a) fucan, showing overall structure of part of a chain, and details of three kinds of linkage; (b) portions of alginic acid (left, polymannuronic acid; right, polyguluronic acid).

Wall-matrix polysaccharide in brown algae

galactose non-sulphated and sulphated polysaccharides

Fucans

(7)

(8)

Fup = L-fucose :

Alginate acid

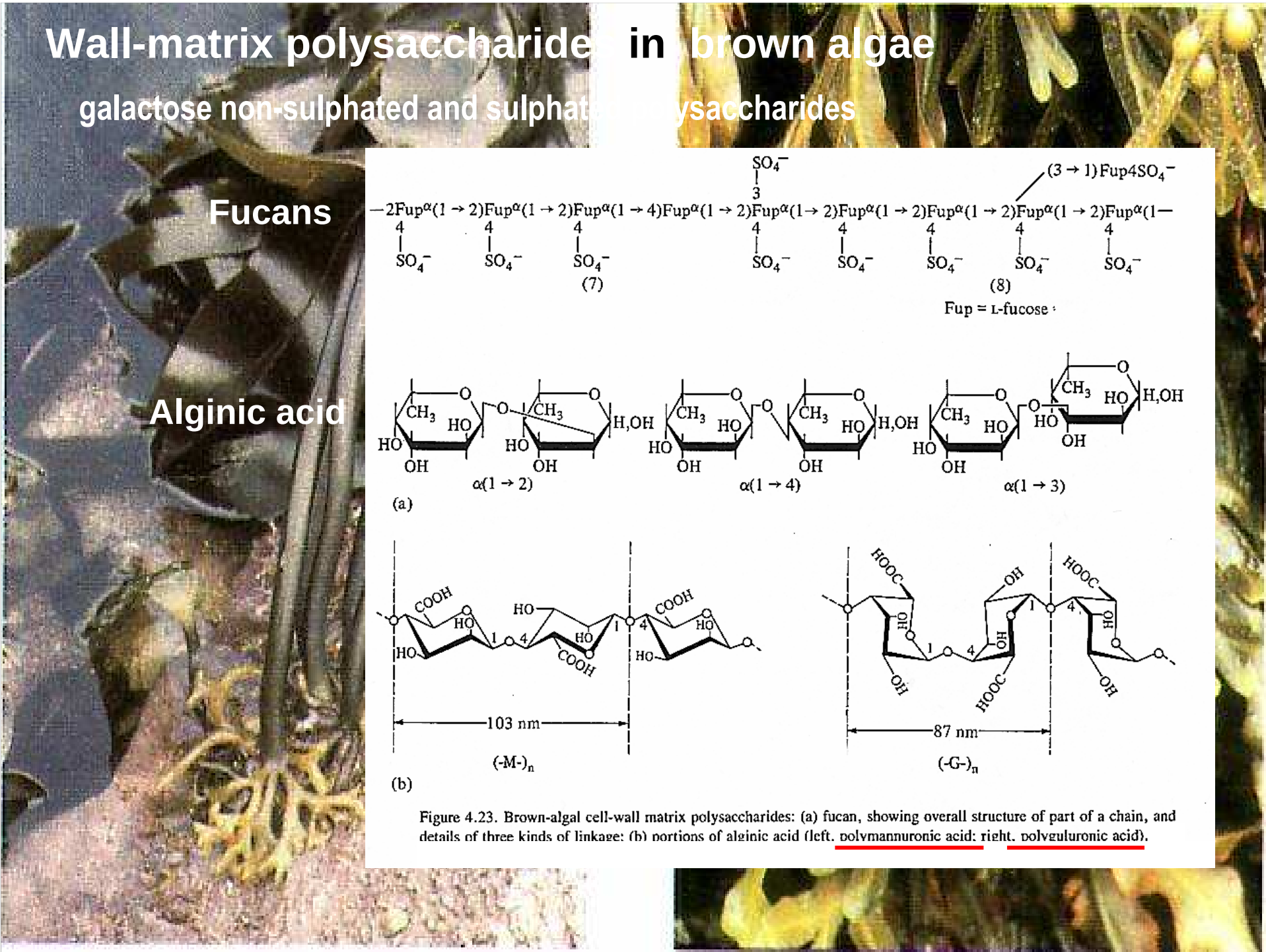
(a)

(b)

(-M-)n

(-G-)n

Figure 4.23. Brown-algal cell-wall matrix polysaccharides: (a) fucan, showing overall structure of part of a chain, and details of three kinds of linkage; (b) portions of alginic acid (left, polymannuronic acid; right, polyguluronic acid).



Wall-matrix polysaccharide in brown algae

galactose non-sulphated and sulphated polysaccharides

Fucans

(7)

(8)

Fup = L-fucose

Alginic acid

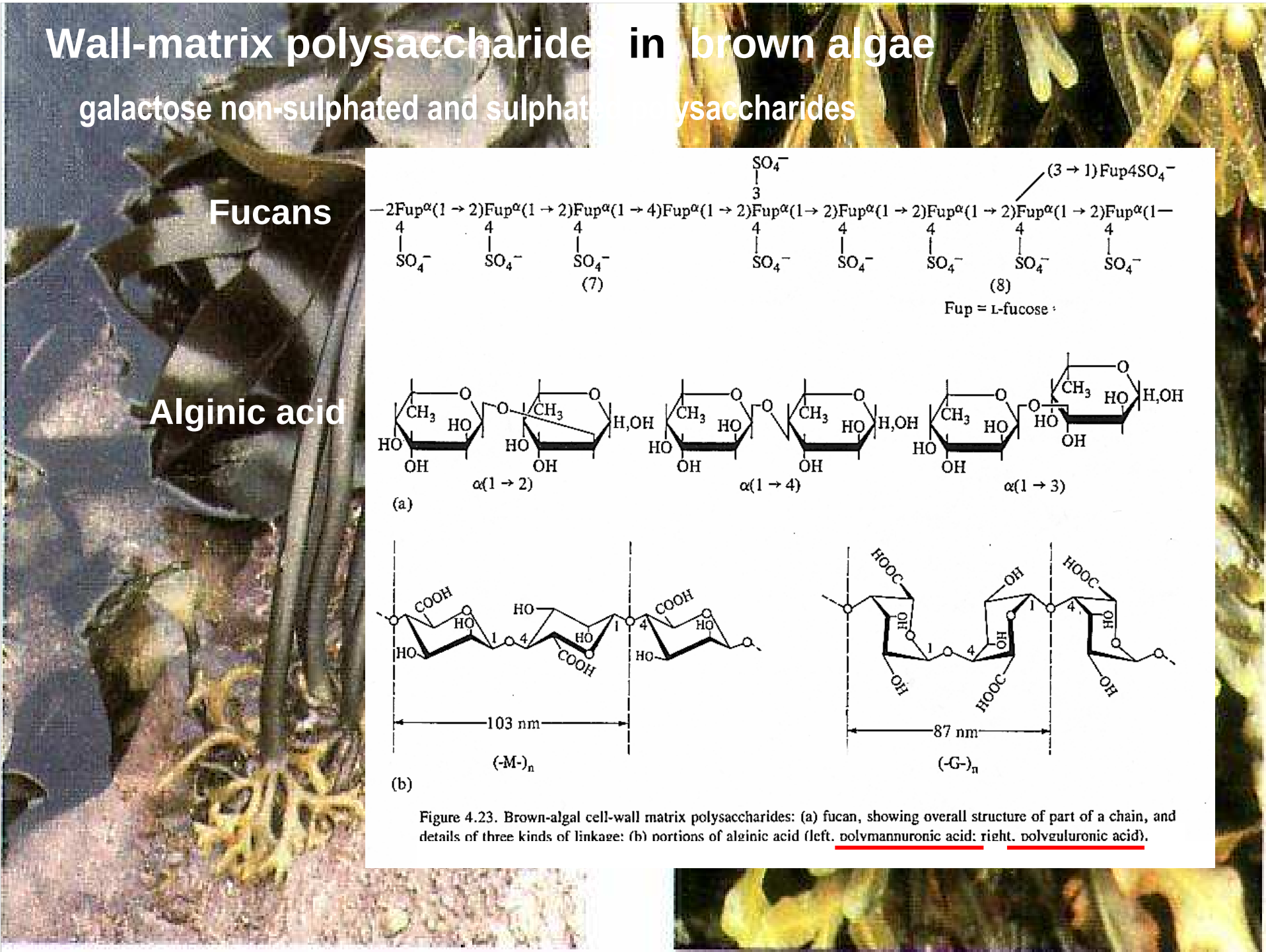
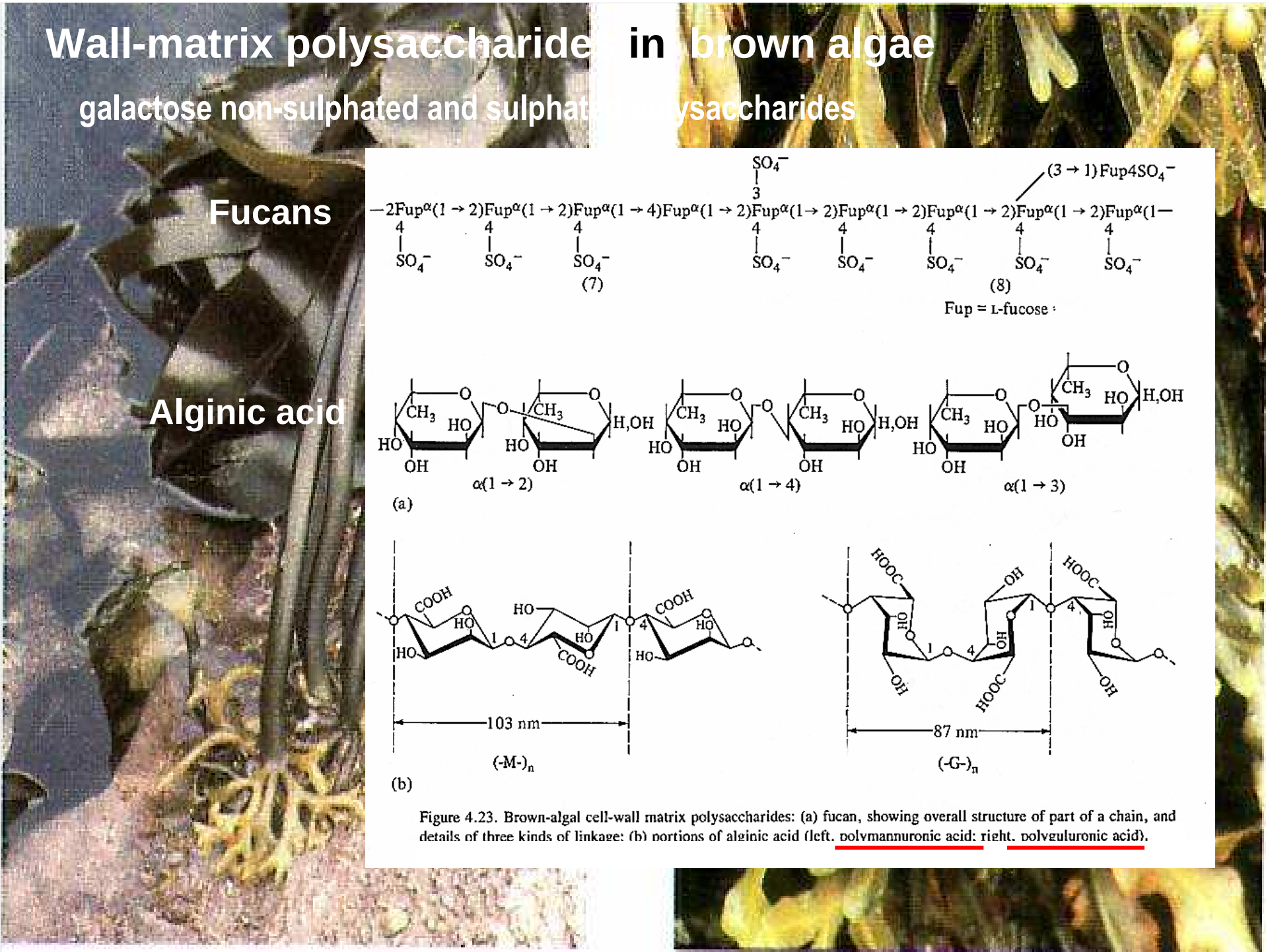
(a)

(b)

(-M-)n

(-G-)n

Figure 4.23. Brown-algal cell-wall matrix polysaccharides: (a) fucan, showing overall structure of part of a chain, and details of three kinds of linkage; (b) portions of alginic acid (left, polymannuronic acid; right, polyguluronic acid).



Wall-matrix polysaccharide in brown algae

galactose non-sulphated and sulphated polysaccharides

Fucans

(7)

(8)

Fup = L-fucose

Alginate acid

(a)

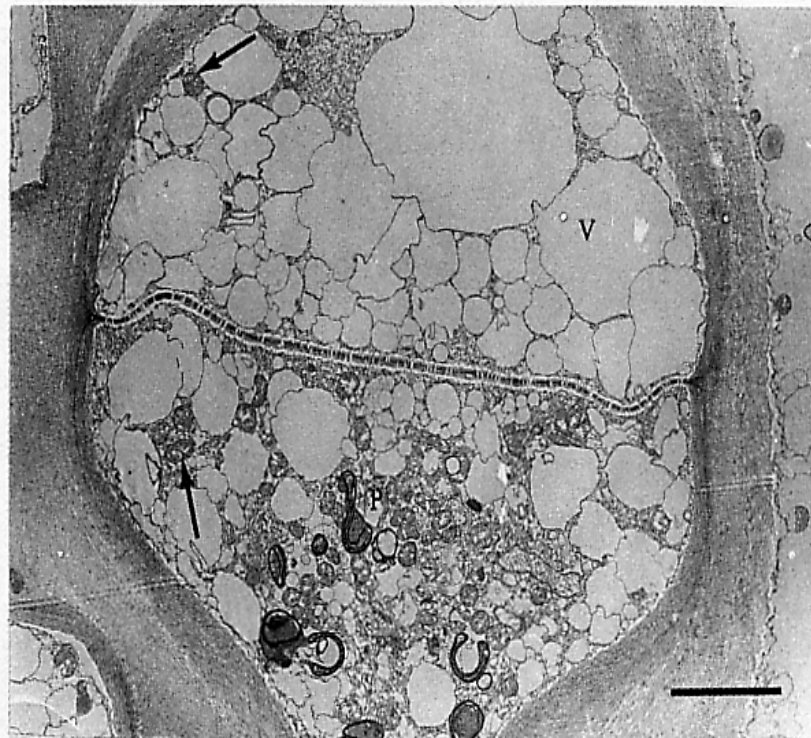
(b)

(-M-)n

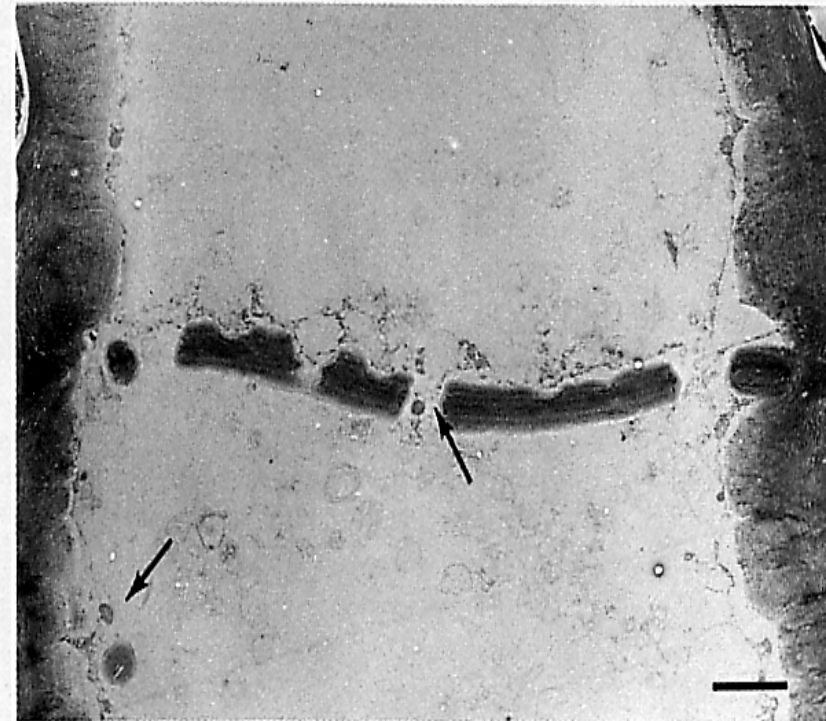
(-G-)n

Figure 4.23. Brown-algal cell-wall matrix polysaccharides: (a) fucan, showing overall structure of part of a chain, and details of three kinds of linkage; (b) portions of alginic acid (left, polymannuronic acid; right, polyguluronic acid).

Carbon translocation in brown algae



(a)



(b)

Figure 4.26. Longitudinal sections through sieve tubes with sieve plates of (a) *Laminaria groenlandica* and (b) *Macrocystis integrifolia*. Mitochondria can be seen in both (arrows); plastids (P) and vacuoles (V) are indicated in *Laminaria*. Note the many narrow pores through the sieve plate of *Laminaria* compared with the few, large pores in *Macrocystis*. Scale = 5 μm .

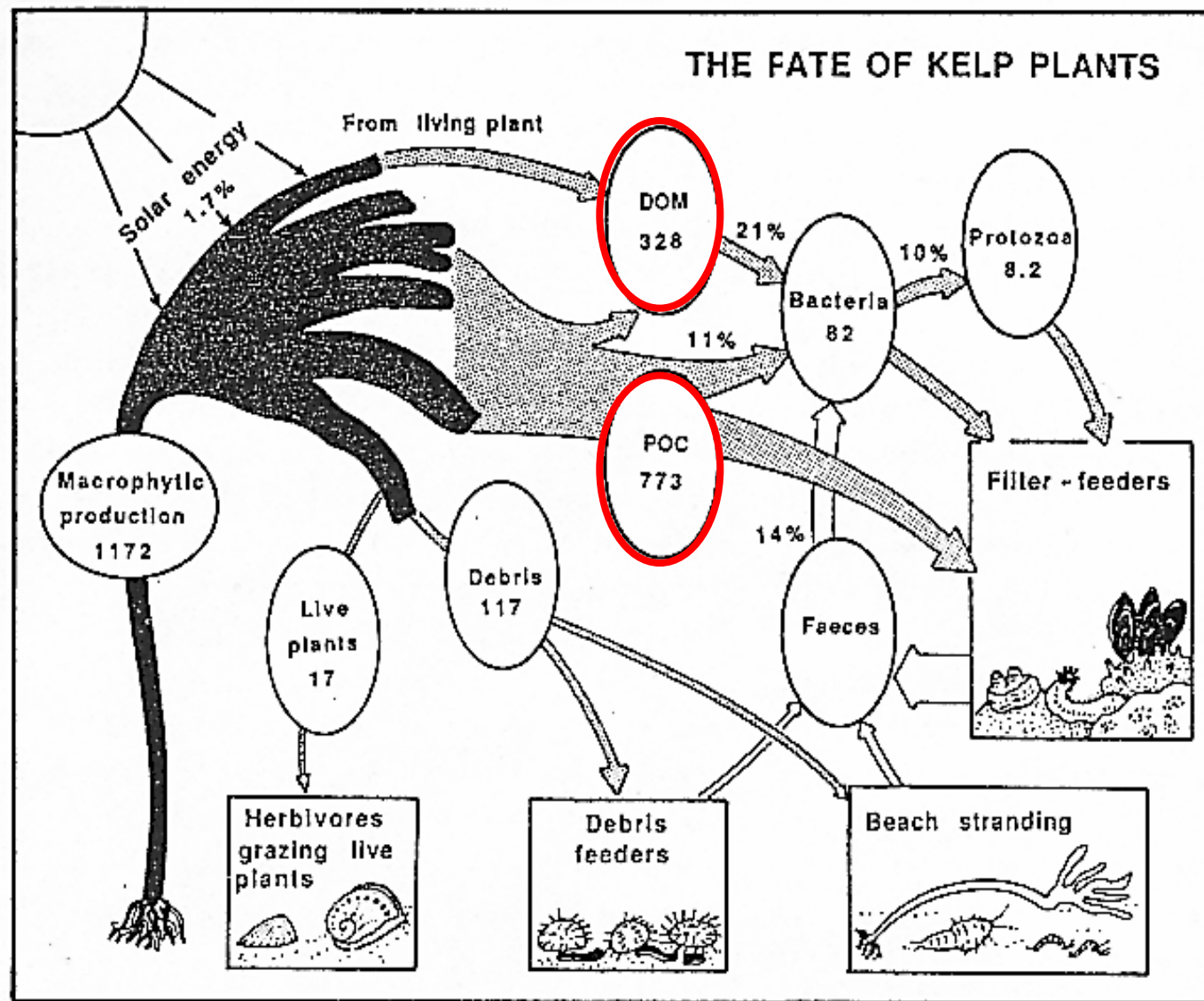


Figure 4.30. Fate of seaweed productivity in the near-shore ecosystem. (a) Kelp production and consumption (grams C per square meter per year). Percentages on the arrows indicate conversion efficiencies between different components. (b) Percentages of carbon photosynthesized by kelps found in tissues of consumers at Alaskan islands with extensive subtidal kelp beds. Kelp-derived carbon was identified by its $\delta^{13}\text{C}$ signature.