

NUTRIENTI - Elementi chimici essenziali

- necessari per crescita e completamento ciclo riproduttivo
- non possono essere sostituiti da altri elementi
- effetto diretto su organismo, no interazione con altri

O₂ atmosferico disciolto in acqua :

- concentrazione dipende da salinità e temperatura (> a basse T e in acqua dolce)
- variazioni dipendono da attività biologica (fotosintesi, respirazione, ossidazione detrito organico)

Al limite inferiore della zona eufotica:

- profondità di compensazione (O₂ evoluto = O₂ respirato)

Al di sotto, tasso consumo O₂ cresce e tra 500-1000 m in acque pelagiche o sul fondo si ha solo attività chemiosintetica e anaerobia (H₂S)

Anossia in bacini isolati (scarsità rimescolamento): Mar Nero

NUTRIENTS

macro-

micro-

Table 5.1. *Functions and compounds of the essential elements in seaweeds*

Element	Probable functions	Examples of compounds
Nitrogen	Major metabolic importance in compounds	Amino acids, purines, pyrimidines, amino sugars, amines
Phosphorus	Structural, energy transfer	ATP, GTP, etc., nucleic acids, phospholipids, coenzymes (including coenzyme A), phosphoenolpyruvate
Potassium	Osmotic regulation, pH control, protein conformation and stability	Probably occurs predominantly in the ionic form
Calcium	Structural, enzyme activation, cofactor in ion transport	Calcium alginate, calcium carbonate
Magnesium	Photosynthetic pigments, enzyme activation, cofactor in ion transport, ribosome stability	Chlorophyll
Sulfur	Active groups in enzymes and coenzymes, structural	Methionine, cystine, glutathione, agar, carrageenan, sulfolipids, coenzyme A
Iron	Active groups in porphyrin molecules and enzymes	Ferredoxin, cytochromes, nitrate reductase, nitrite reductase, catalase
Manganese	Electron transport in photosystem II, maintenance of chloroplast membrane structure	
Copper	Electron transport in photosynthesis, enzymes	Plastocyanin, amine oxidase
Zinc	Enzymes, ribosome structure(?)	Carbonic anhydrase
Molybdenum	Nitrate reduction, ion absorption	Nitrate reductase
Sodium	Enzyme activation, water balance	Nitrate reductase
Chlorine	Photosystem II, secondary metabolites	Violacene
Boron	Regulation of carbon utilization(?), ribosome structure(?)	
Cobalt	Component of vitamin B ₁₂	B ₁₂
Bromine ^a Iodine ^a	{ Toxicity of antibiotic compounds(?)	{ Wide range of halogenated compounds, especially in Rhodophyceae

^aPossibly an essential element in some seaweeds.

Composizione chimica dell'acqua di mare

L'acqua di mare contiene circa 34.8 g di sali disciolti per kg

CLORURO DI SODIO	g. 27,213/litro
CLORURO DI MAGNESIO	g. 3,807/litro
SOLFATO DI MAGNESIO	g. 1,658/litro
SOLFATO DI CALCIO	g. 1,260/litro
SOLFATO DI POTASSIO	g. 1,863/litro
CARBONATO DI CALCIO	g. 0,123/litro
BROMURO DI MAGNESIO	g. 0,076/litro

$\text{Cl}^- = \sim 55\%$

$\text{Na}^+ = \sim 31\%$

89 elementi

$\text{mg/Kg} = \text{ppm}$

Nei mari e oceani + Mg, S, Ca, K, Br, C, Sr, B, F (concentrazioni simili in regioni diverse)

Nei laghi < Ca e HCO_3^- (concentrazioni anche molto diverse)

Table 5.2 Concentrations of some essential elements in seawater and in seaweeds

Element	Mean concentration in seawater		Concentration in dry matter		Ratio of concentration in seawater to concentration in tissue
	(mmol kg ⁻¹)	(µg g ⁻¹)	Mean (µg g ⁻¹)	Range (µg g ⁻¹)	
<i>Macronutrients</i>					
H	105,000	10,500	49,500	22,000–72,000	2.1 × 10 ⁰
Mg	53.2	1,293	7,300	1,900–66,000	1.8 × 10 ⁻¹
S	28.2	904	19,400	4,500–8,200	4.7 × 10 ⁻²
K	10.2	399	41,100	30,000–82,000	1.0 × 10 ⁻²
Ca	10.3	413	14,300	2,000–360,000	2.9 × 10 ⁻²
C	2.3	27.6 ^{a,b}	274,000	140,000–460,000	1.0 × 10 ⁻⁴
B	0.42	4.50	184	15–910	2.4 × 10 ⁻²
N	0.03	0.420 ^{a,c}	23,000	500–65,000	2.1 × 10 ⁻⁵
P	0.002	0.071	2,800	300–12,000	2.4 × 10 ⁻⁵
<i>Micronutrients</i>					
Zn	6 × 10 ⁻⁶	0.0004 ^a	90	2–680	4.4 × 10 ⁻⁵
Fe	1 × 10 ⁻⁶	0.00006 ^a	300	90–1,500	1.0 × 10 ⁻⁵
Cu	4 × 10 ⁻⁶	0.0002 ^a	15	0.6–80	1.7 × 10 ⁻⁴
Mn	0.5 × 10 ⁻⁶	0.00003 ^a	50	4–240	2.0 × 10 ⁻⁵

^aConsiderable variation occurs in seawater (Bruland 1983).

^bDissolved inorganic carbon.

^cCombined nitrogen (dissolved organic and inorganic).

Redfield ratio (1958):

analisi composizione chimica del fitoplancton marino indicano rapporti atomici tra **C:N:P** in condizioni di attiva crescita pari a **106:16:1**

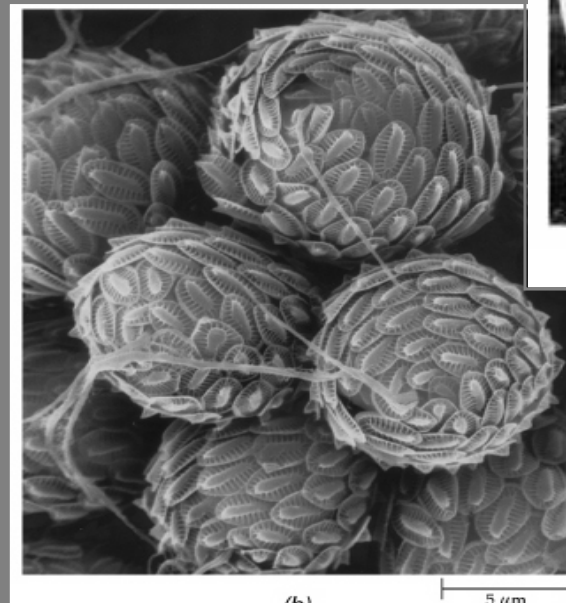
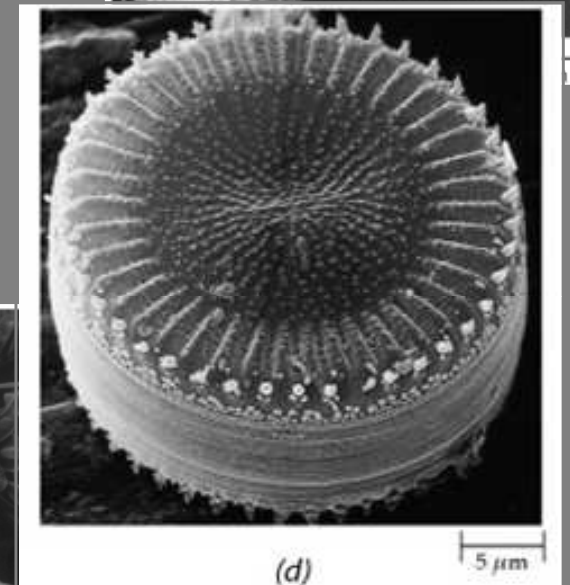
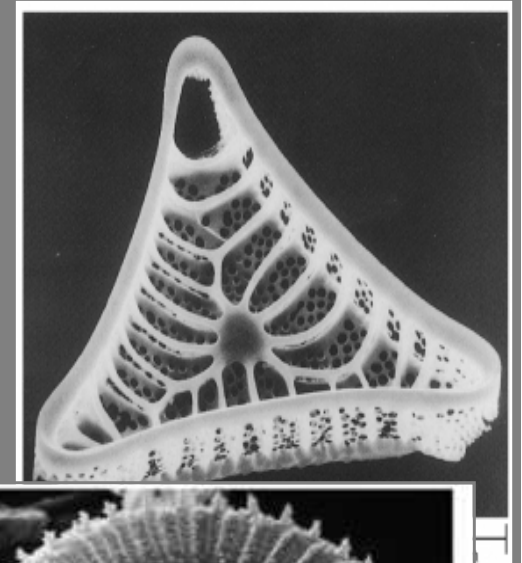
Microalghe che necessitano di Si (diatomee, crisoficee, silicoflagellati)
106C:16N:16Si:1P

Macroalghe **550C:30N:1P**

A tali condizioni nessuno di questi nutrienti è limitante.
Deviazioni da questi rapporti vengono usate per inferire limitazione da parte di alcuni elementi

Deprivazione da P a rapporti N/P >30

Deprivazione da N a valori <10



Interazioni con i nutrienti

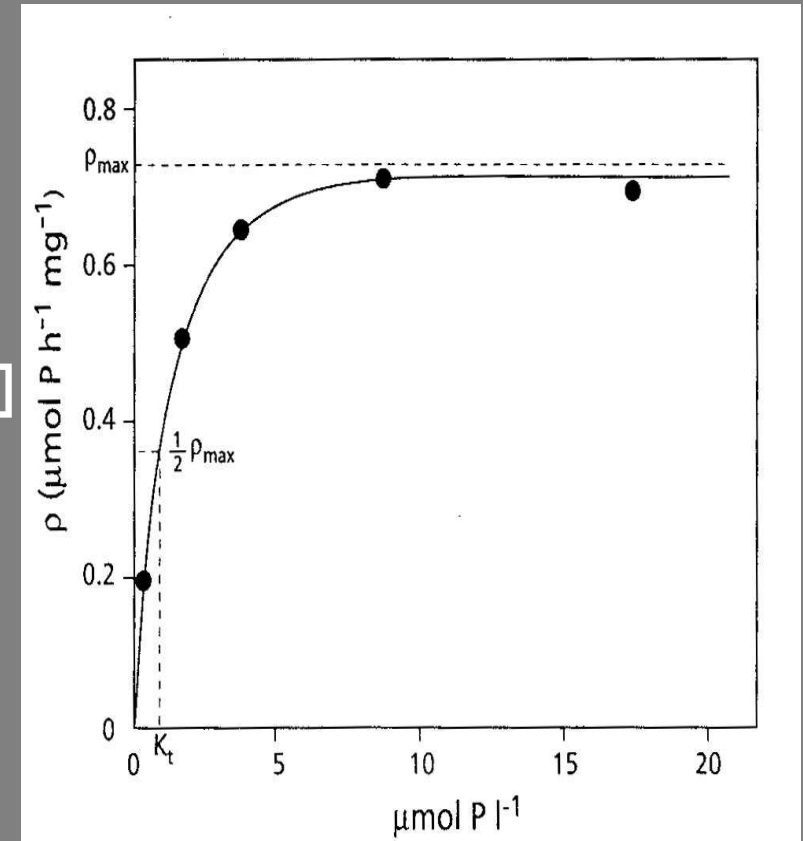
I processi di assimilazione di ioni (uptake) possono verificarsi per:

- diffusione passiva
 - diffusione facilitata
 - trasporto attivo
- } seguono la cinetica enzimatica
velocità max quando $[ext] \gg [int]$

La max concentrazione interna di un nutriente [int.]

- capacità accumulo fissata geneticamente
- varia con dimensioni cellulari

favorite specie con elevato S (area) / V (volume),
aumento rapido di V consente maggiore accumulo



Nutrient uptake and algal growth

Michaelis-Menton model of uptake:

$$\rho = \rho_{\max} \{S/(S + K_t)\}$$

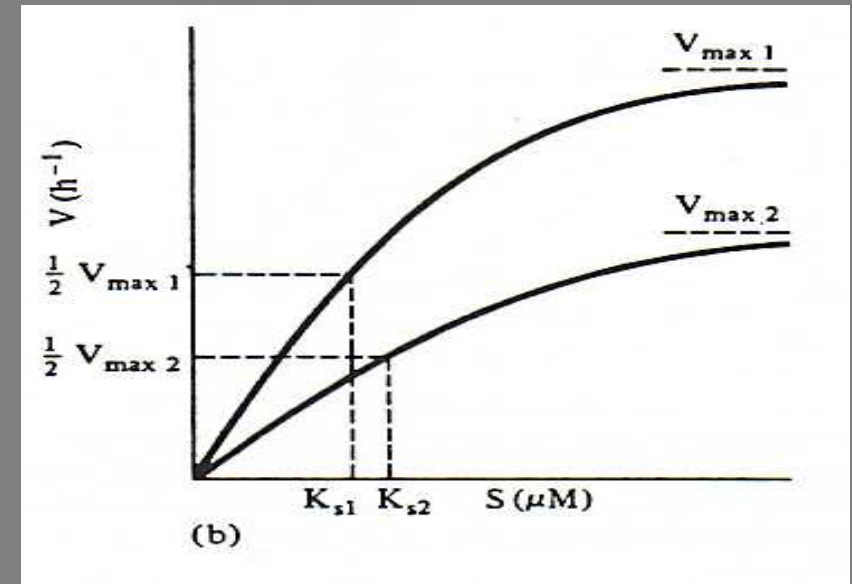
where ρ is the rate of uptake

$\rho_{\max}$ is the maximum rate of uptake

S is the concentration of the nutrient

K_t is the half-saturation concentration

rate of uptake = $\mu\text{moles cell}^{-1} \text{ min}^{-1}$



Monod model of cell growth based on nutrient concentration:

$$\mu = \mu_{\max} \{S/(S + KS)\}$$

where μ is the growth rate

$\mu_{\max}$ is the maximum growth rate

S is the concentration of the nutrient

KS is the half-saturation concentration for growth

growth = $\mu\text{moles L}^{-1} \text{ min}^{-1}$

Droop model of growth as a function of internal nutrient stores:

$$\mu = \mu_{\max} \{1 - Q_0/Q\}$$

where Q is the internal concentration of the nutrient

Q_0 is some minimal concentration necessary before reproduction can occur

units for Q and Q_0 = $\mu\text{moles cell}^{-1}$

NITROGEN CYCLE IN THE SEA

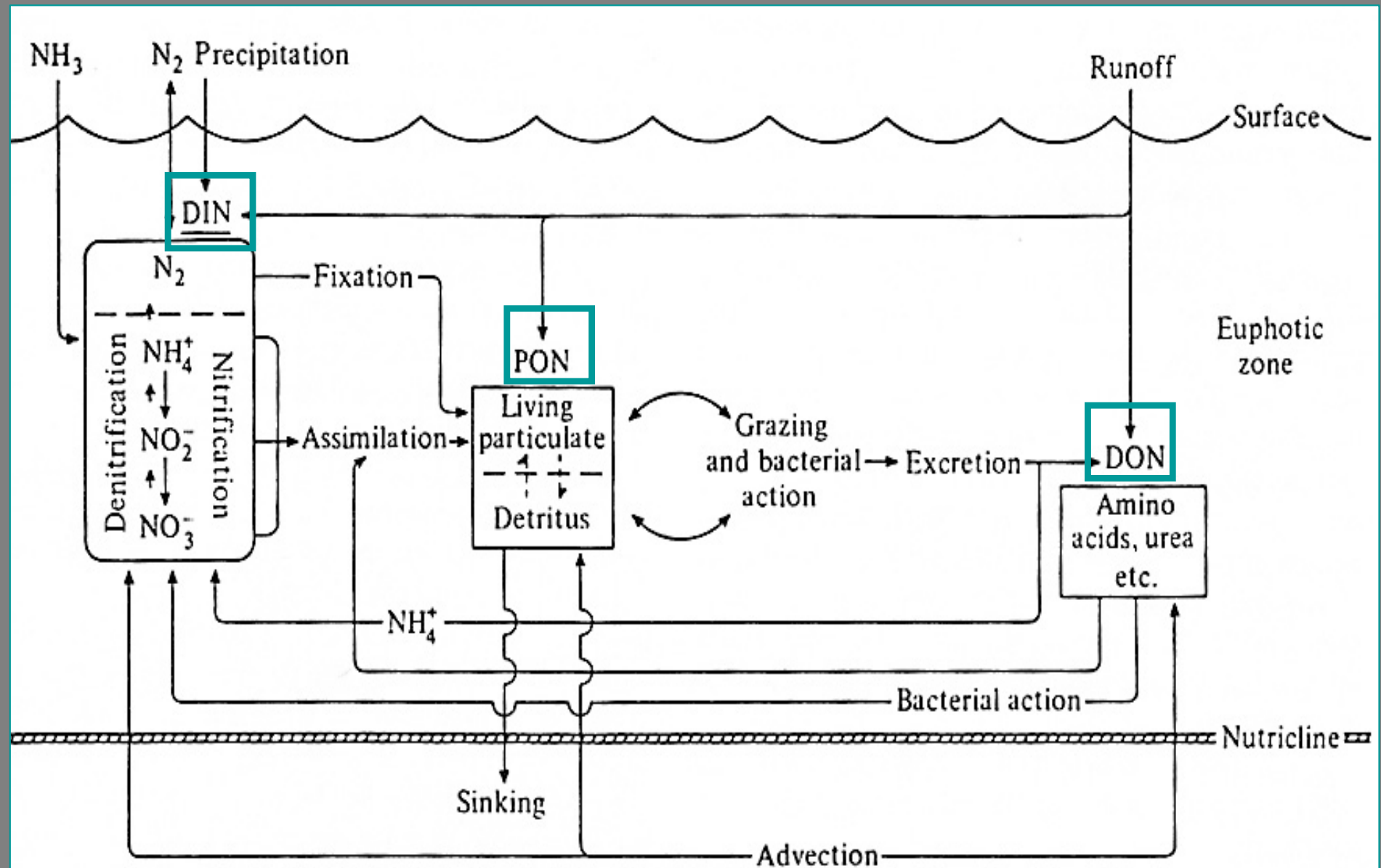


Figure 5.2. Schematic representation of the nitrogen cycle of the sea. PON, particulate organic nitrogen; DON, dissolved organic nitrogen; DIN, dissolved inorganic nitrogen.

Nitrogen metabolism

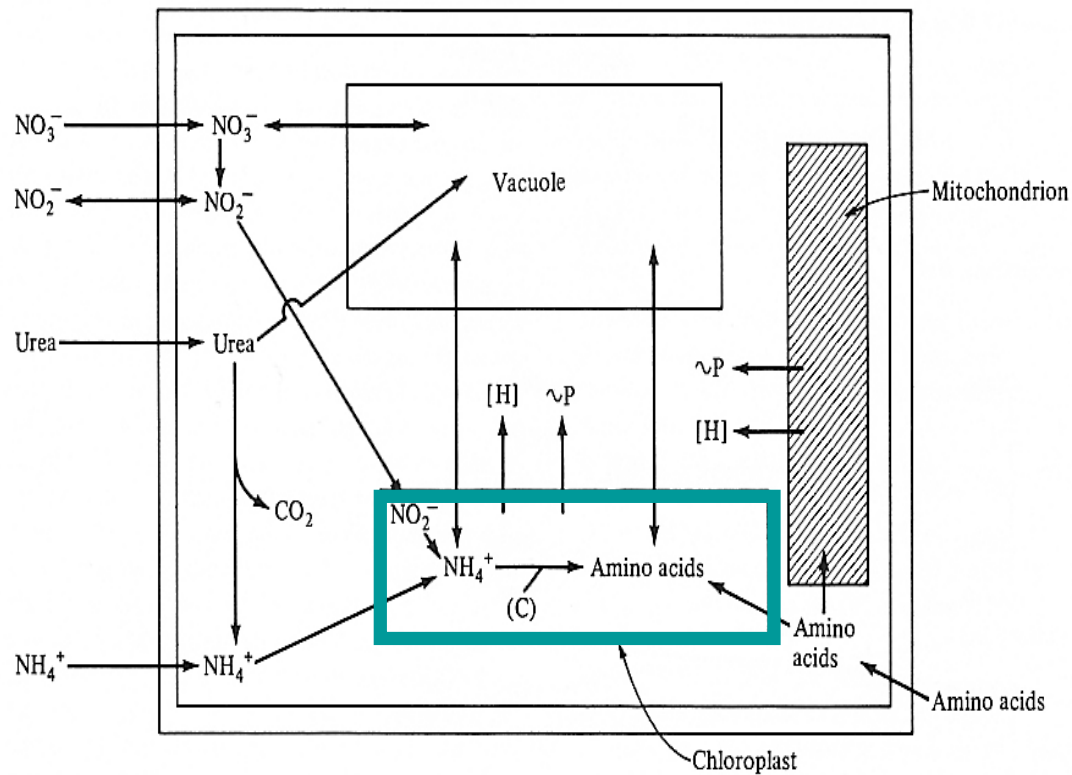
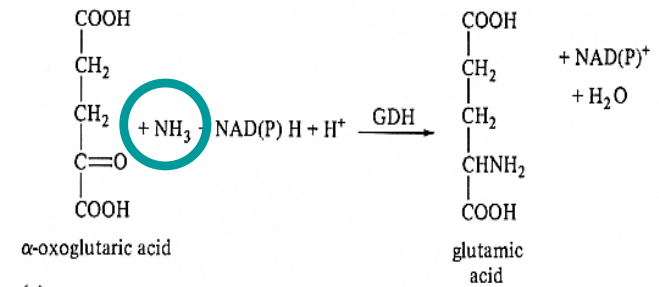
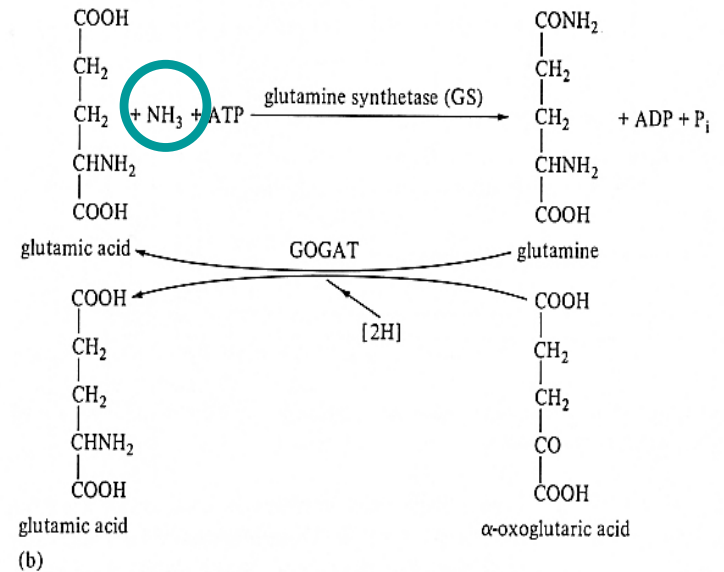


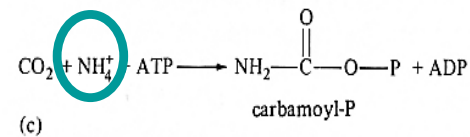
Figure 5.8. Main features of nitrogen uptake and assimilation in a eukaryotic algal cell.



(a)

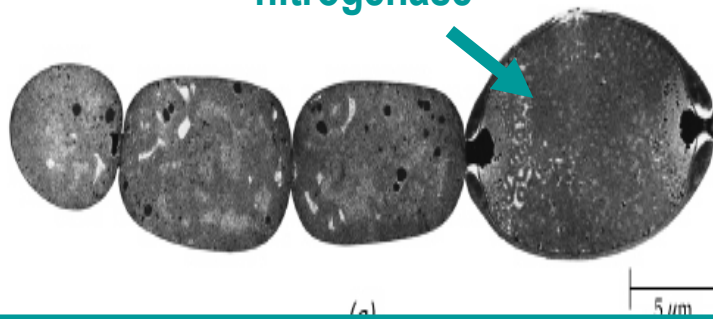


(b)



(c)

nitrogenase



Nitrogen fixation (N_2) in cyanobacteria:

- in heterocysts or aggregates (spatial separation)
- during dark (temporal separation)

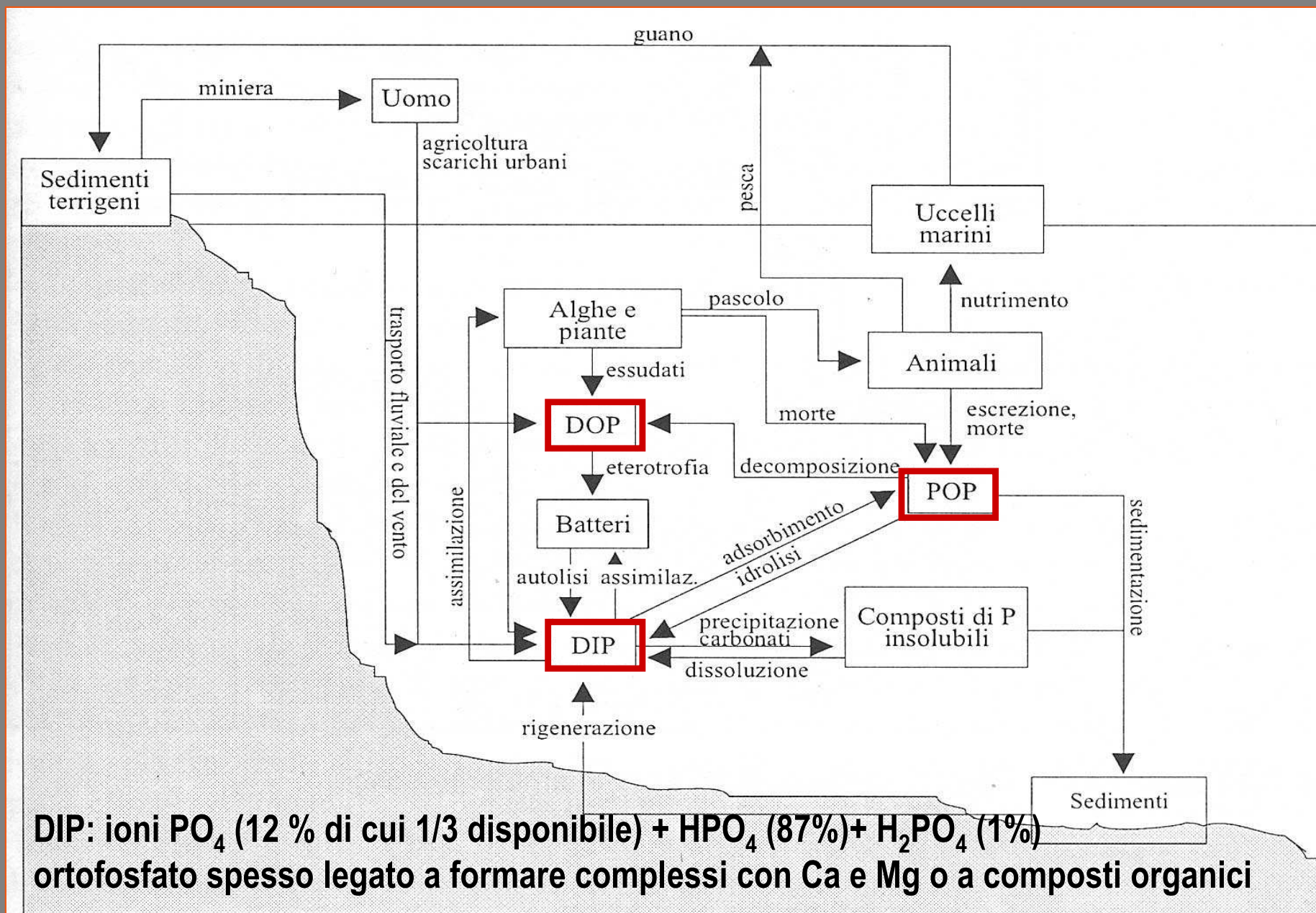
Table 5.4. Examples of nitrogen-uptake kinetic "constants" for seaweeds

Alga	Temperature (°C)	NO ₃ ⁻		NH ₄ ⁺	
		K _s ± SE (μM)	V _{max} (μmol g _{dw} ⁻¹ h ⁻¹)	K _s ± SE (μM)	V _{max} (μmol g _{dw} ⁻¹ h ⁻¹)
Phaeophyceae:					
<i>Fucus spiralis</i>	5	6.6 ± 0.9		6.4 ± 2.0	
	10	6.7 ± 0.8		5.4 ± 2.0	
	15	7.8 ± 1.4		9.6 ± 2.6	
	15 ^a	12.8 ± 3.5		5.8 ± 1.8	
<i>Fucus distichus</i>	15	1–5	25	3–5	60
<i>Laminaria longicruris</i>	15 ^b	4.1	9.6		
	10 ^c	5.9	7.0		
<i>Macrocystis pyrifera</i>	16	13.1 ± 1.6	30.5	5.3 ^f ± 1.0	23.8 ^f
	6–9			50 ^g	23.6 ^g
<i>Chordaria flagelliformis</i>	11	5.9 ± 1.2	8.8		
<i>Laminaria groenlandica</i>	13		20 ^d		20
			6 ^e		6
Rhodophyceae:					
<i>Gracilaria foliifera</i>	20	2.5 ± 0.5	9.7	1.6 ^f	23.8 ^f
<i>Agardhiella subulata</i>	20	2.4 ± 0.3	11.7	3.9 ^f	15.9 ^f
<i>Hypnea musciformis</i>	26	4.9 ± 3.9	28.5	16.6 ± 1.8	
<i>Chondrus crispus</i>	17			35.5	62
<i>Porphyra perforata</i>	12		15		40–50
Chlorophyceae:					
<i>Chaetomorpha linum</i>	25		60		230
<i>Enteromorpha prolifera</i>	12–14	2.3–13.3	75–169	9.3–13.4	39–188
<i>Enteromorpha</i> spp.	15	16.6	129.4		
<i>Codium fragile</i>	6	1.9 ± 0.5	2.8	1.5 ± 0.2	13.0
	24	7.6 ± 0.6	9.6	1.4 ± 0.2	28.0
<i>Ulva lactuca</i>	20			40.7 ± 8.5	138 ± 78
<i>Ulva rigida</i>	25	20–33	60–90		60

^aDark.^bSummer tissue.^cWinter tissue.^dFirst-year plants.^eSecond- and third-year plants.^fMechanism-1 uptake (high-affinity system).^gUptake of methylamine, an analogue of NO₄⁺.

Ciclo P

maggior riserva di fosforo nelle rocce contenenti fosfati (liberati per erosione)
consumatori utilizzano P da fitoplancton (rilasciato per escrezione e morte)
P accumulato in sedimenti sotto forma particellata (PIP) o insolubile



Phosphorous as Phosphate

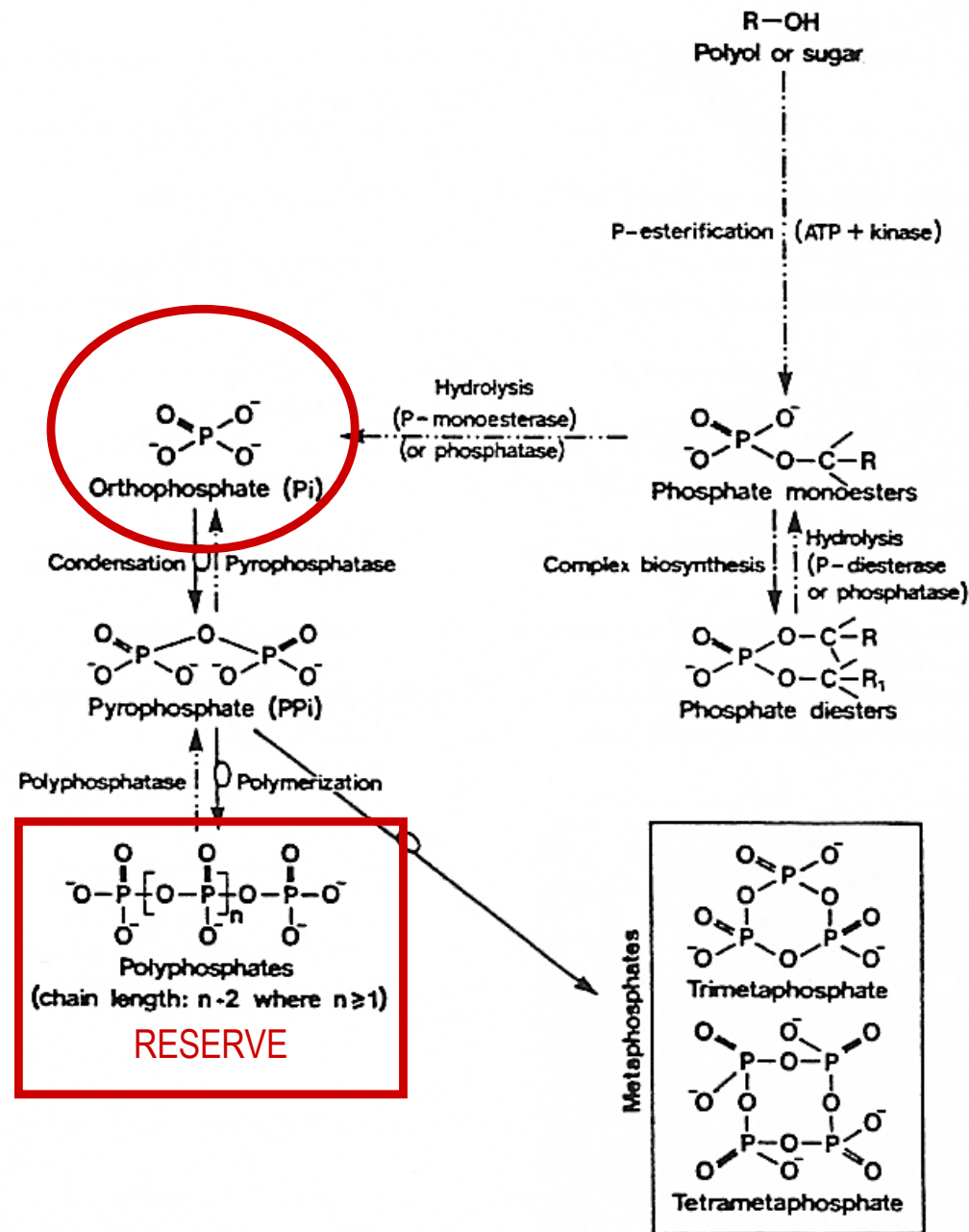
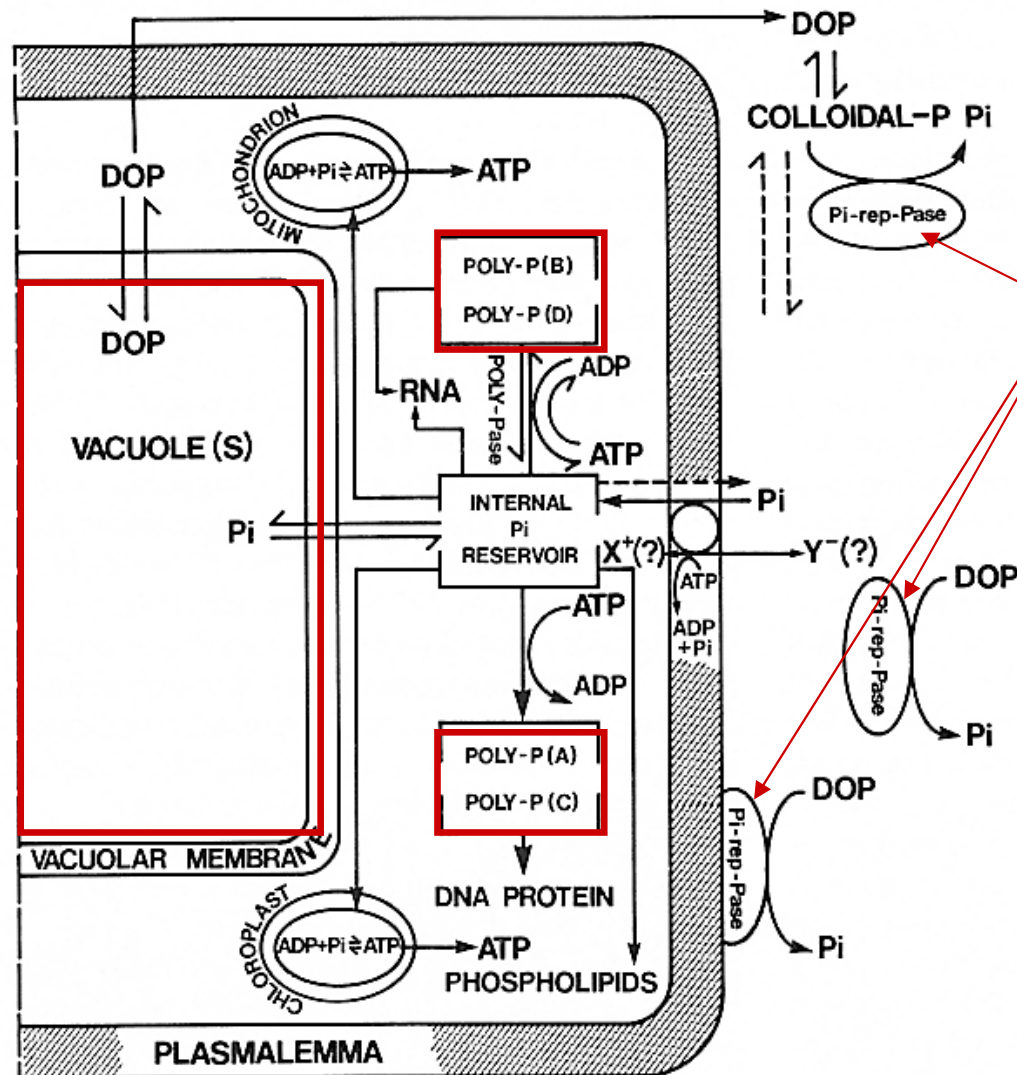


Figure 5.11. Interconversion of inorganic- and organic-phosphate storage compounds

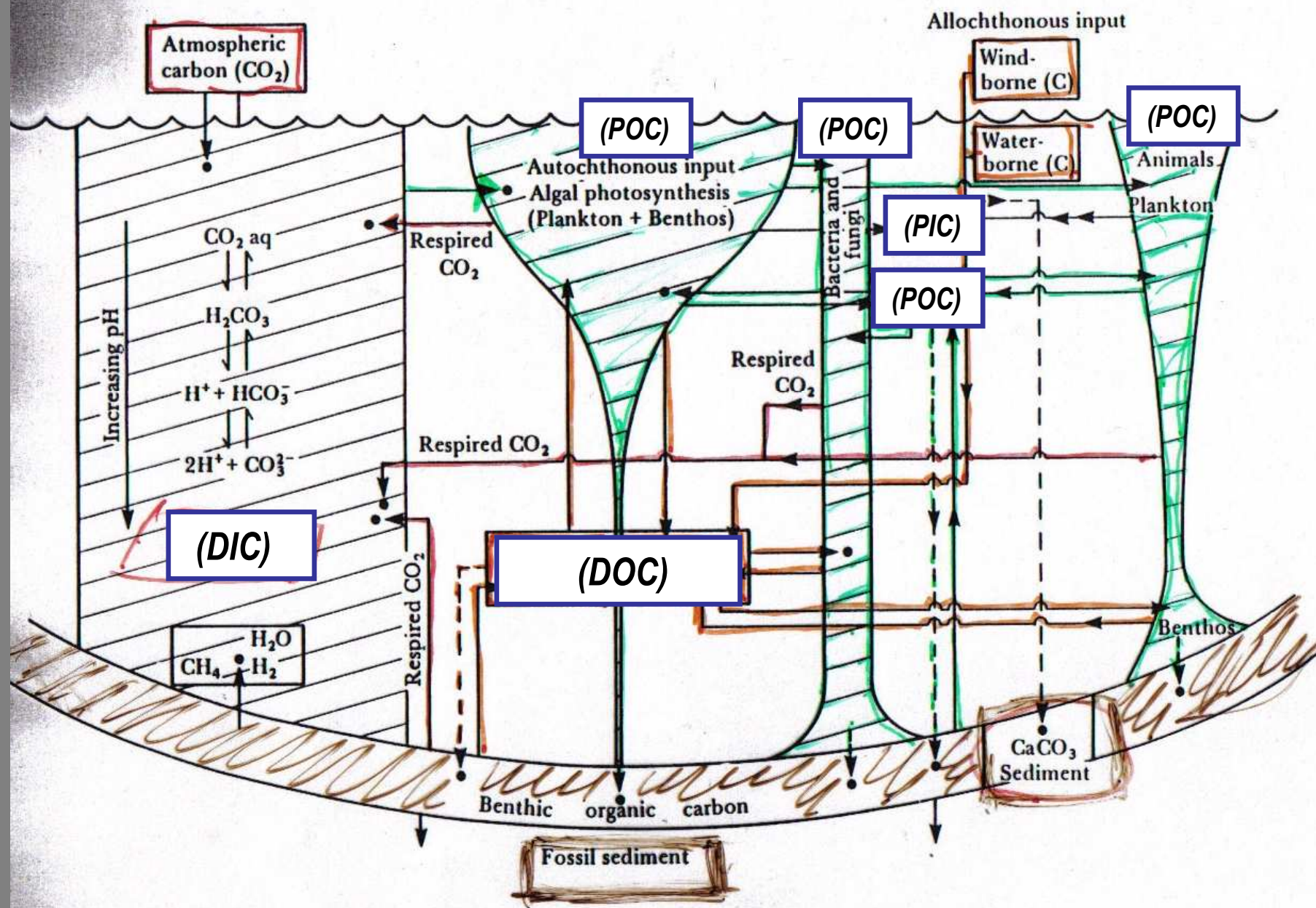
Phosphate metabolism



Alkaline Phosphatases

Figure 5.10. Main features of phosphorus uptake and assimilation in a microalgal cell. DOP, dissolved organic phosphate; Pi, inorganic phosphate.

Fig. 11.6. Sources of carbon and flow through aquatic organisms. Dashed lines represent deposition pathways and solid lines transfer between pools.

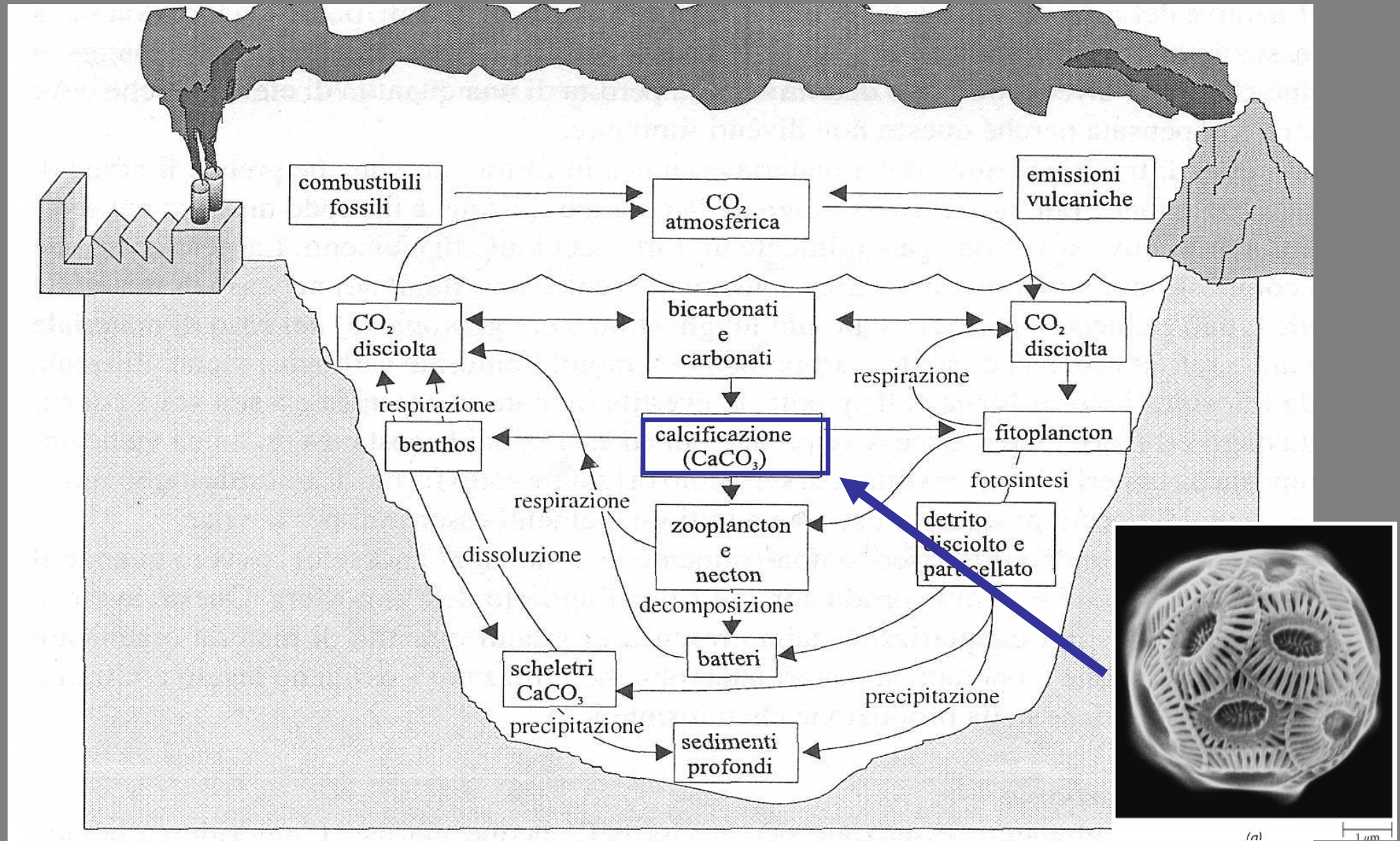


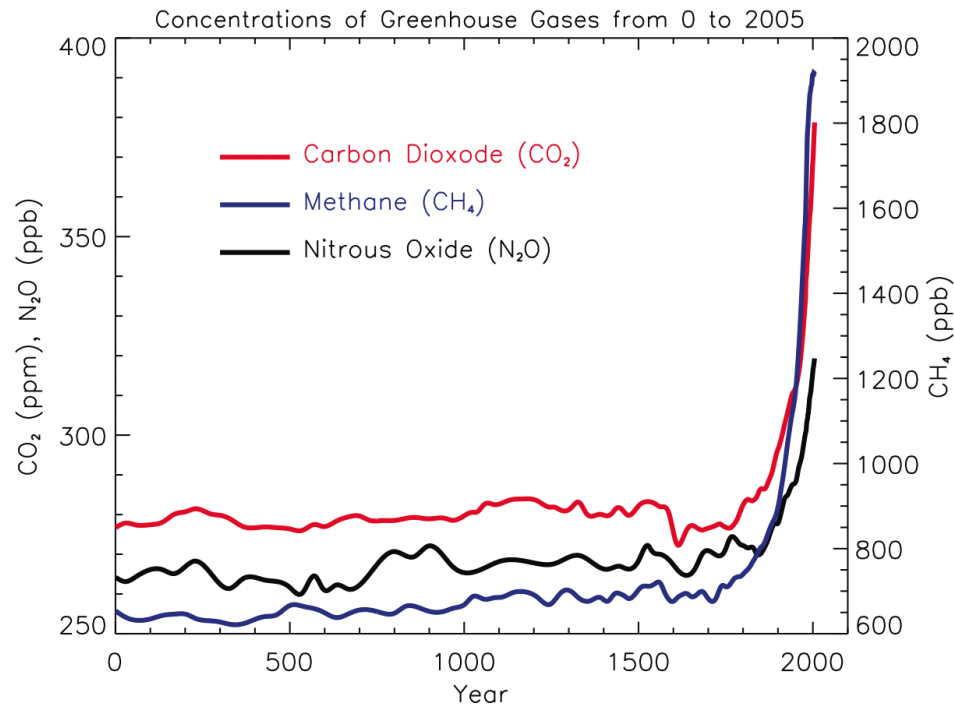
Ciclo C

CO_2 molto solubile in H_2O

$\text{pH} < 6$ C presente come CO_2 o H_2CO_3 non disciolti,

$\text{pH} > 6$ HCO_3^-

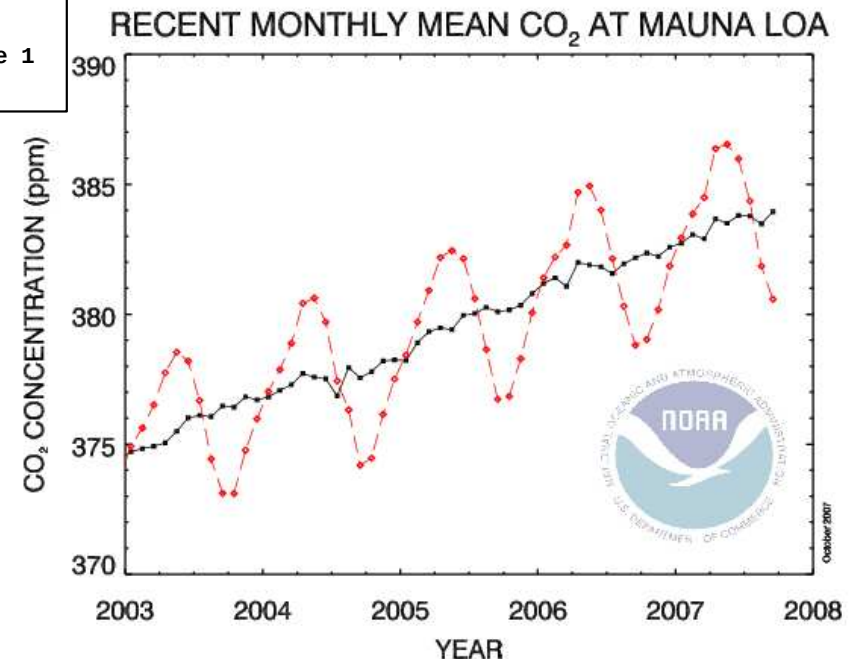




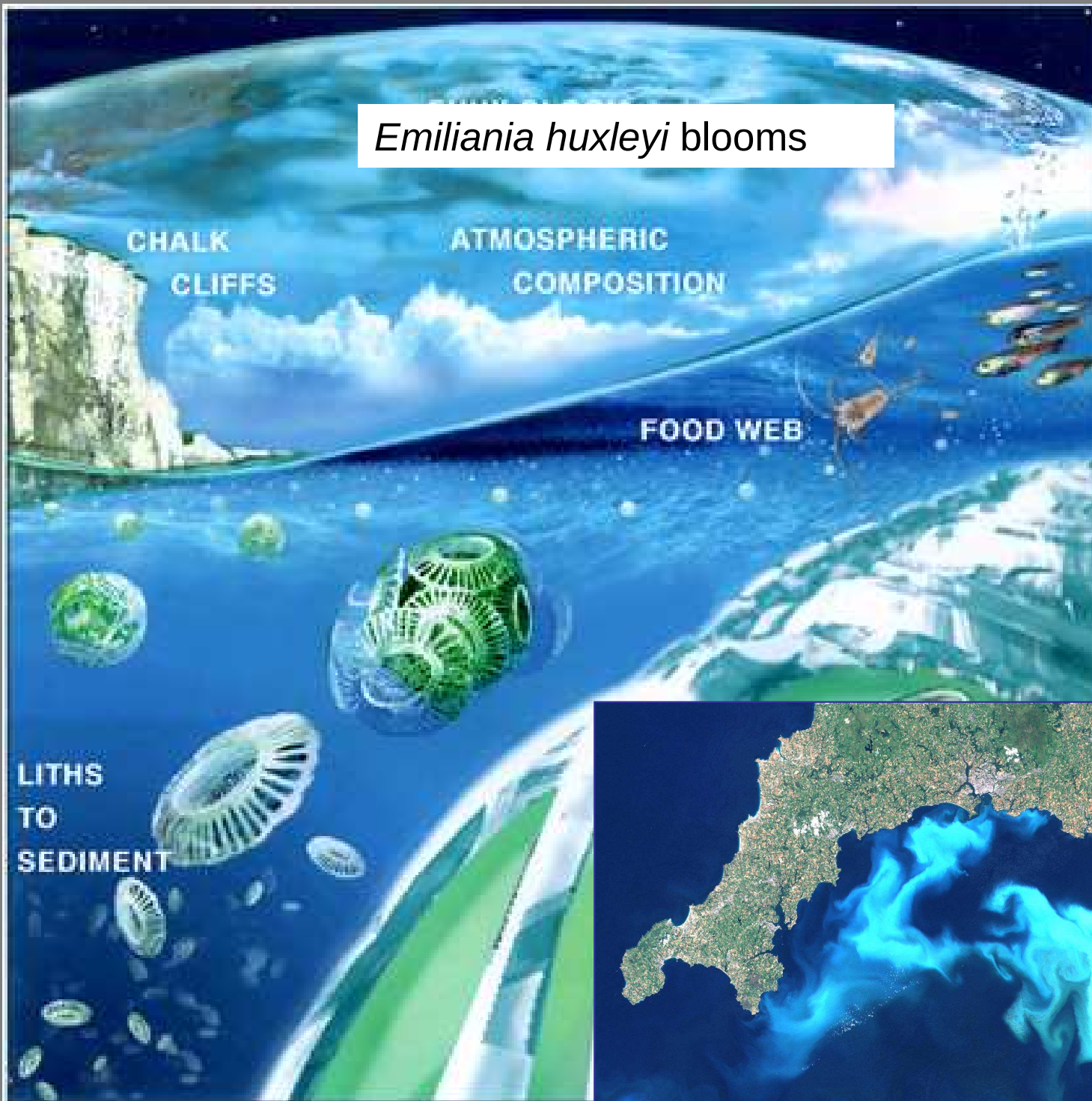
FAQ 2.1, Figure 1

Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Increases since about 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in an atmospheric sample.

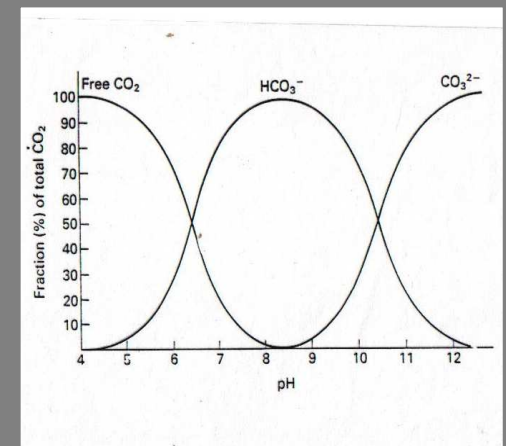
Atmospheric CO₂ global increase



Emiliana huxleyi blooms



E. huxleyi, often abbreviated to simply "EHUX", is a species of coccolithophore with a global distribution from the tropics to subarctic waters. It is studied for the extensive blooms it forms in nutrient depleted waters after the reformation of the summer thermocline.



Sink for CO₂

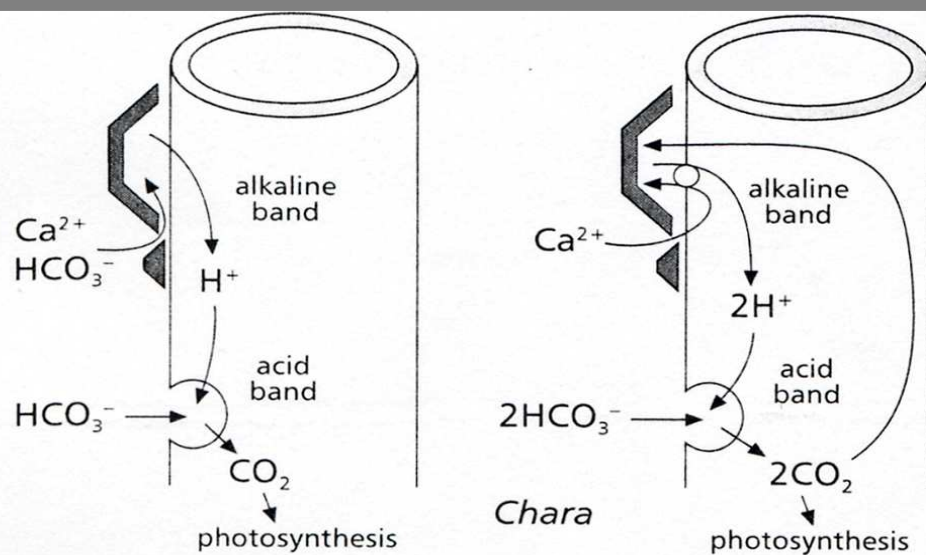
Calcium and calcification in algae

- Mantenimento delle membrane cellulari
- Ruolo nella morfogenesi e nella chemiotassi
- Elemento strutturale della parete
- Coinvolto nel sistema dei messaggeri e attivazione enzimatica
- Deposizione sotto forma di CaCO_3 :

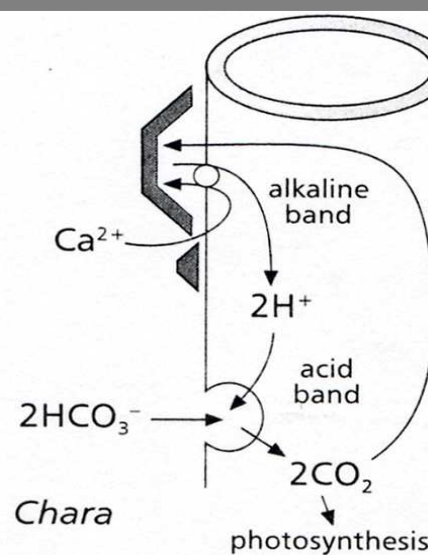
CALCITE o ARAGONITE

cyanobacteria ↑

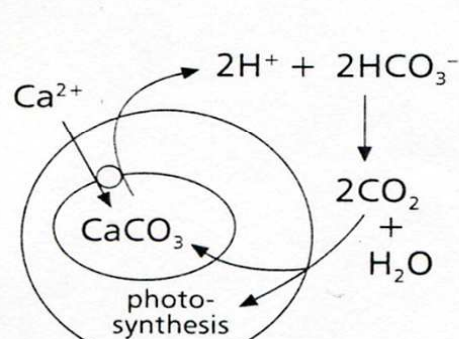
Sites	Forms	Examples of taxa
Extracellular		
Cell-wall surface	Concentric bands of fine aragonite needles on cell surface	<i>Padina</i> (Dictyotaceae)
Intercellular	Surface encrustation of calcite crystals Fine aragonite needles in intercellular spaces in utricles Intercellular crystals of aragonite and/or calcite that may form small bundles	<i>Chaetomorpha</i> (Cladophoraceae) <i>Halimeda</i> , <i>Udotea</i> (Halimedaceae), <i>Neomeris</i> (Dasycladaceae) <i>Liagora</i> (Liagoraceae), <i>Galaxaura</i> (Galaxauraceae)
Sheath	Bundles of aragonite needles in external sheath Irregular bundles of needle-like crystals, usually aragonite	<i>Penicillus</i> , <i>Udotea</i> (Udoteaceae) <i>Plectonema</i> (Oscillatoriaceae)
Within cell walls	Calcite crystals, often clearly oriented	<i>Lithophyllum</i> , <i>Lithothamnion</i> (Corallinaceae)
Intracellular	Calcified plates (coccoliths) of various forms, usually calcite; formed within Golgi vesicles	<i>Emiliana</i> , <i>Cricosphaera</i> (Prymnesiophyceae)



(a)

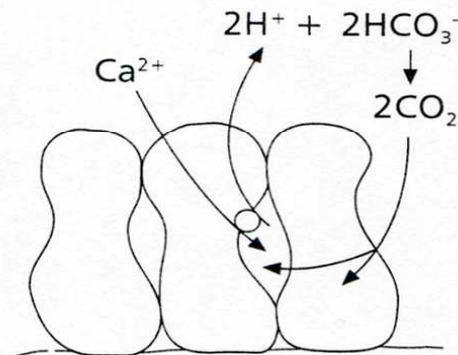


(b)



coccolithophorid

(c)

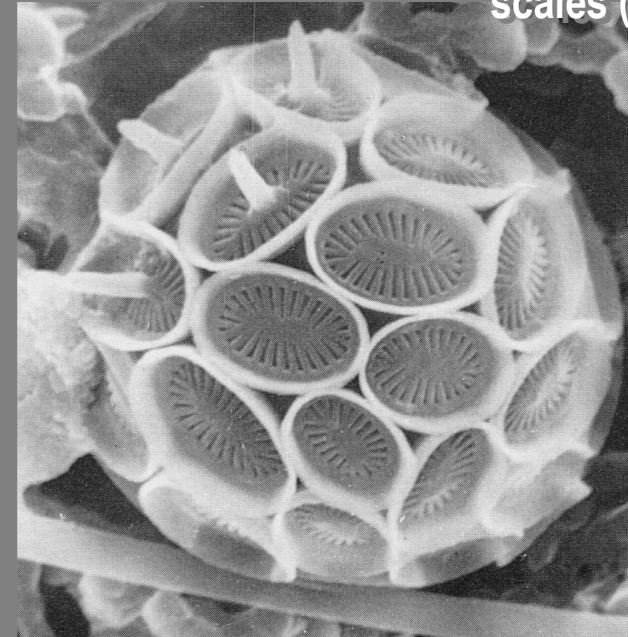


coralline alga

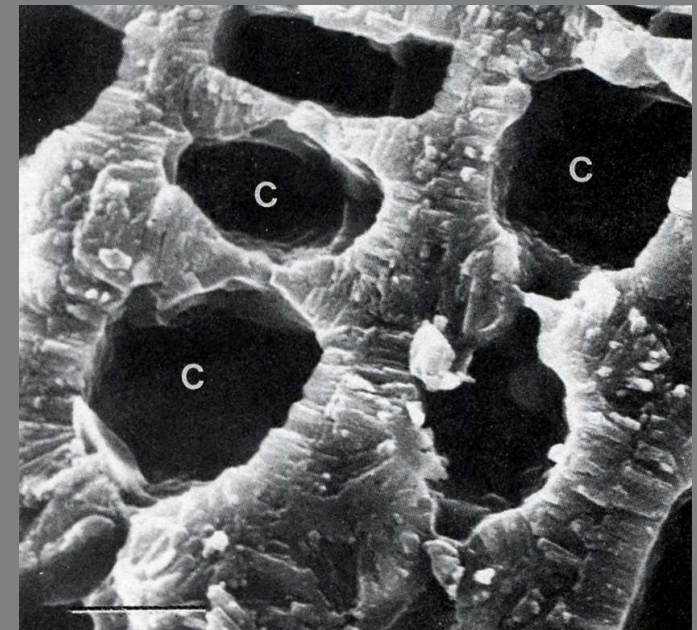
(d)

Figure 2-13 Models of the calcification process in three groups of algae: the green algal genus *Chara*, the coccolithophorids, and red algae known as corallines. Calcification of *Chara* (alternate possibilities are shown in (a) and (b) and corallines (d) occurs externally, whereas this process occurs within intracellular vesicles of coccolithophorids (c). In each case Ca^{2+} transport across a membrane is thought to be linked to export of H^+ , which participates in the extracellular conversion of bicarbonate (HCO_3^-) to CO_2 that is subsequently taken up by cells for use in photosynthesis.

Calcite in Coccolithophorid scales (from Golgi)



Calcite crystal in *Lithotamnion australe* cell wall



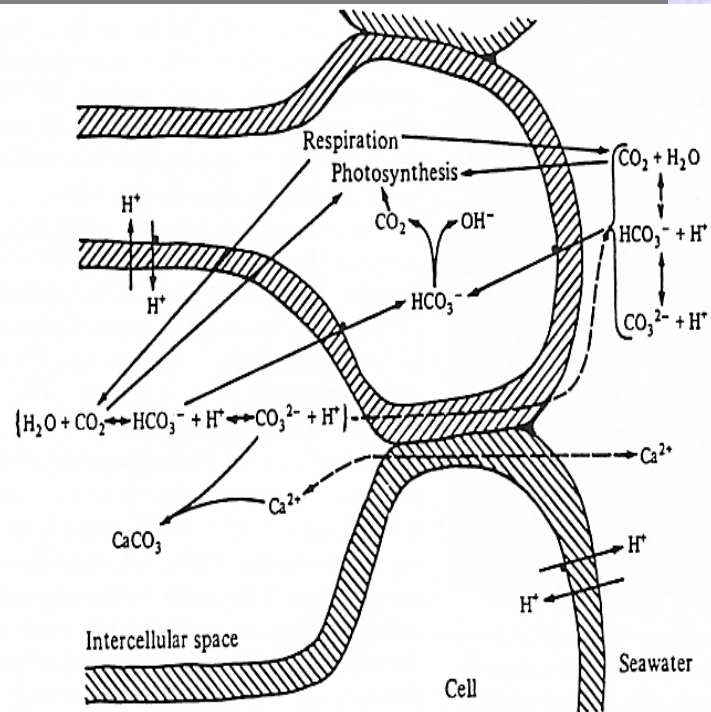
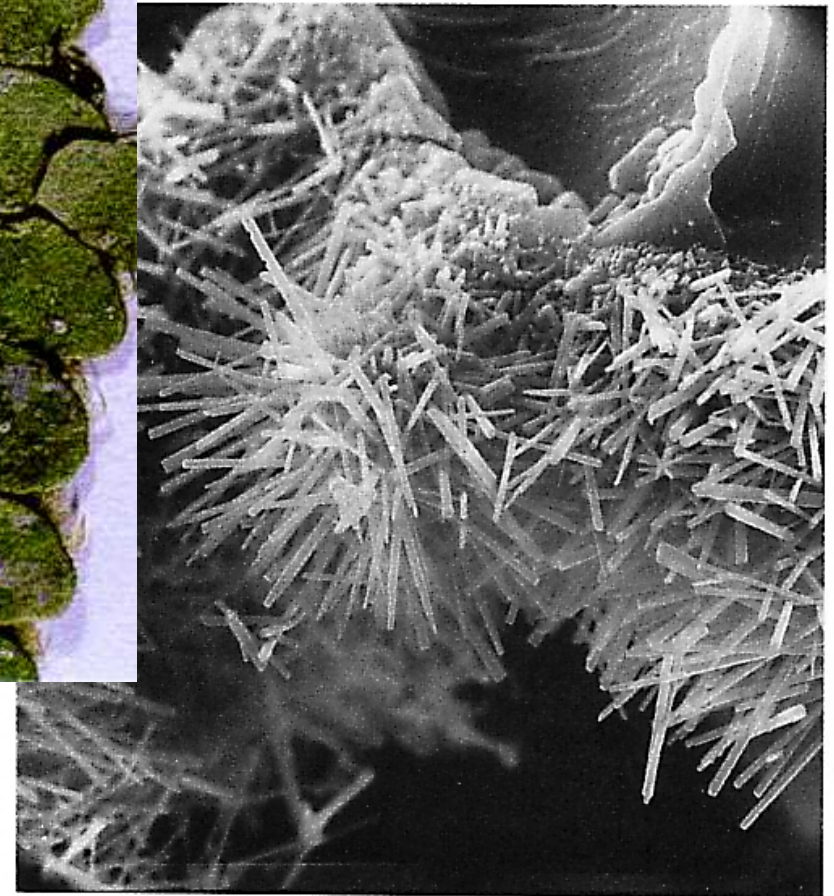
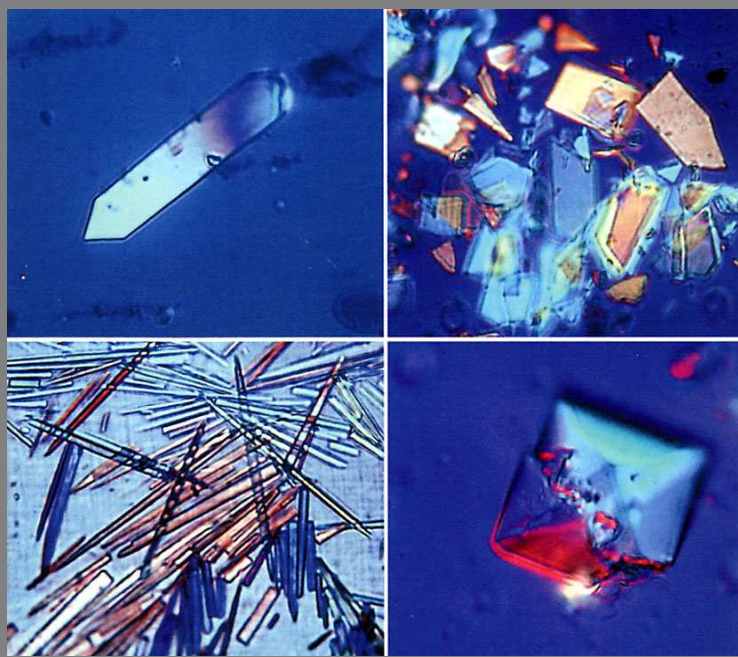


Figure 5.13. Schematic representation of the postulated ion fluxes affecting calcium carbonate precipitation in *Halimeda*. A black dot at the plasmalemma indicates that the flux is postulated to be active.

**Aragonite crystals on
Halimeda cell wall**

Sulphur

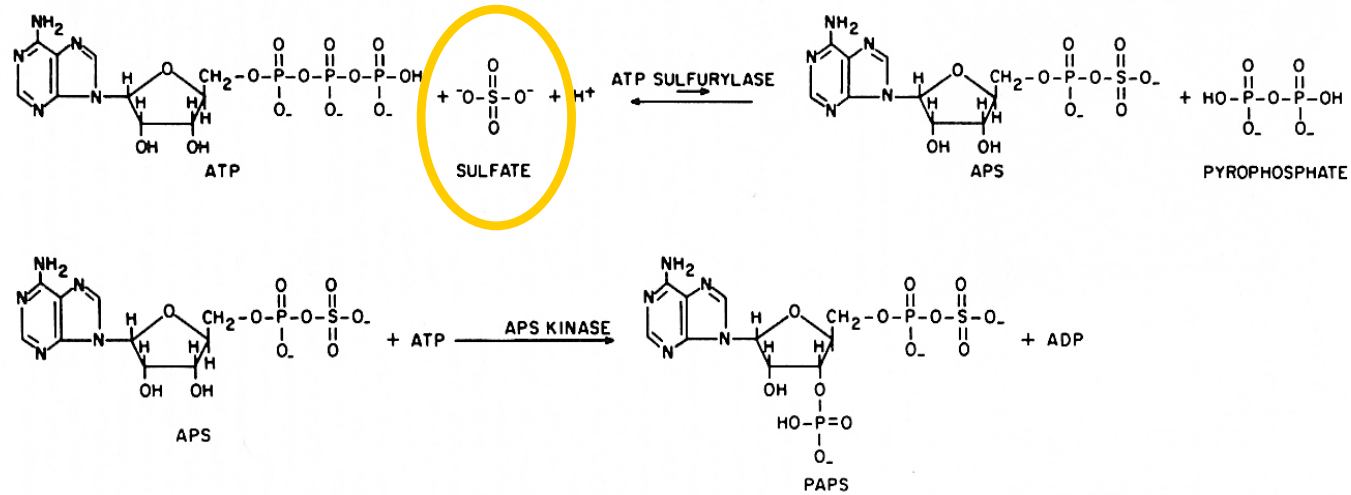
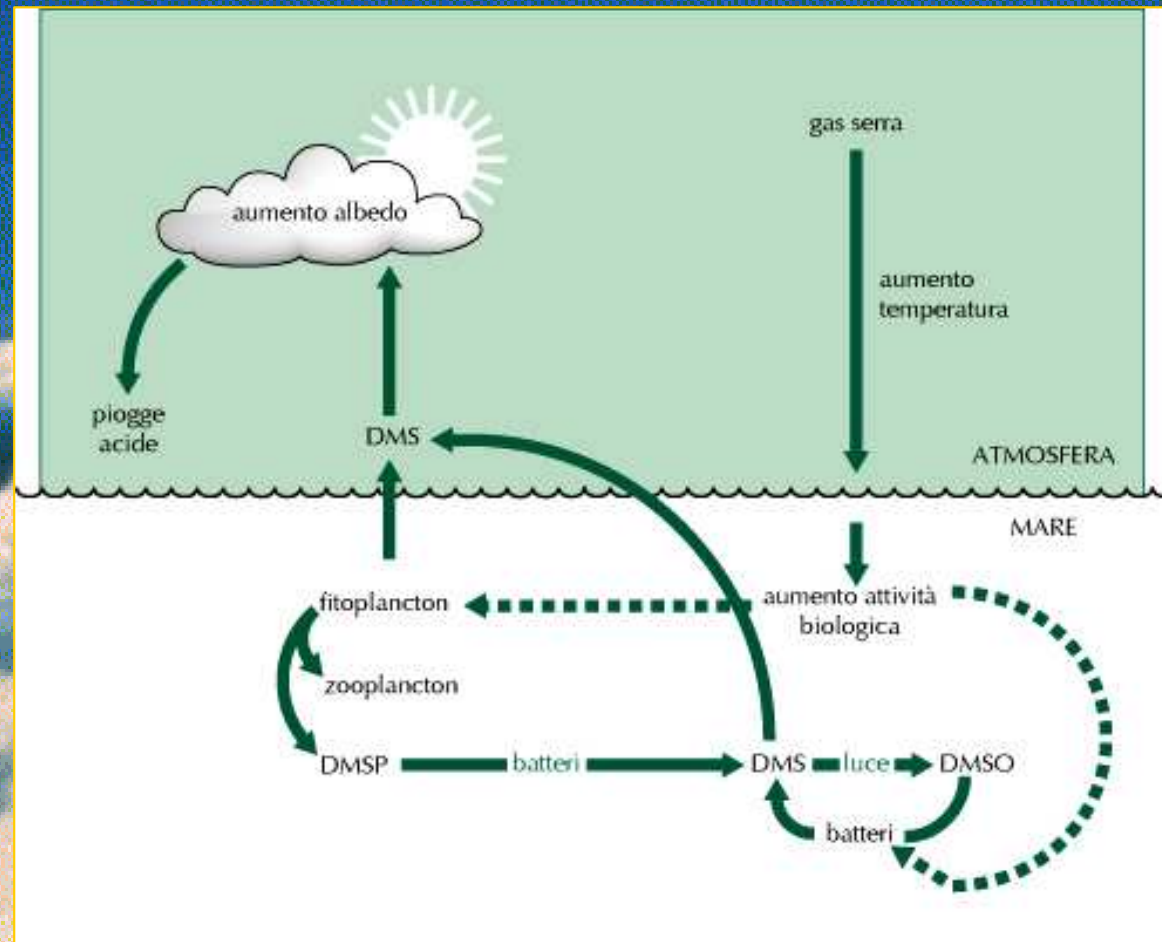


Figure 5.16. Sulfate activation. APS, adenosine-5'-phosphosulfate, PAPS, phosphoadenosine phosphosulfate.

DMSP cycle



Ruolo Fe: in coenzimi trasporto elettroni catene fotosintesi e respirazione, enzimi per fissazione N_2

Fe

4° elemento della crosta terrestre

- metallo poco solubile in acque ricche di ossigeno (a pH marino ione ferrico si combina con idrossili a dare idrossido di ferro relativamente insolubile)
- complessi con agenti chelanti naturali (acidi umici)
- sviluppo e rilascio sostanze intracellulari (porfirine, siderofori) per assimilazione

può limitare la crescita delle alghe: almeno 30% mari del mondo
Studi con mesocosmi, fertilizzazione *in situ*

Si

può limitare crescita diatomee durante stratificazione estiva in ambiente lacustre, causare declino bloom primaverile
densità dei frustuli determina perdita netta di Si su fondali