CYCLES BIOGEOCHIMIQUES

I- CYCLES BIOGEOCHIMIQUES

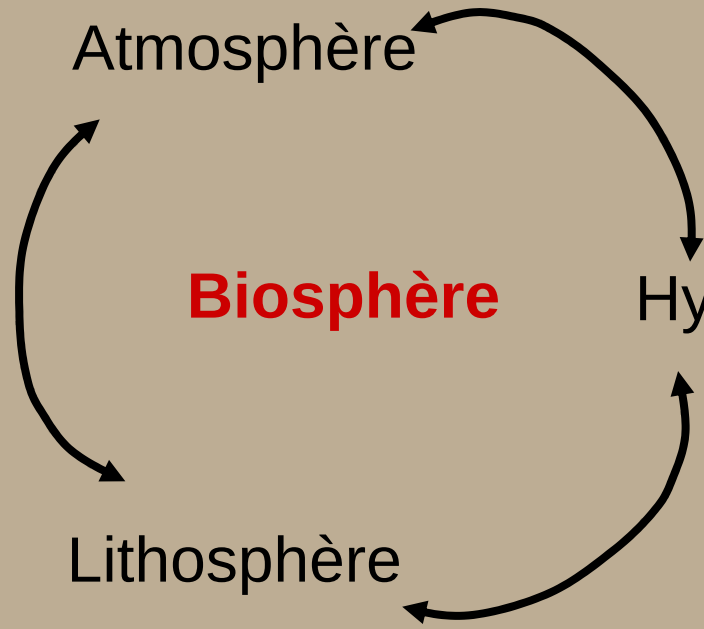
1- Carbone

2- Azote

3- Manganèse et fer

4- Soufre

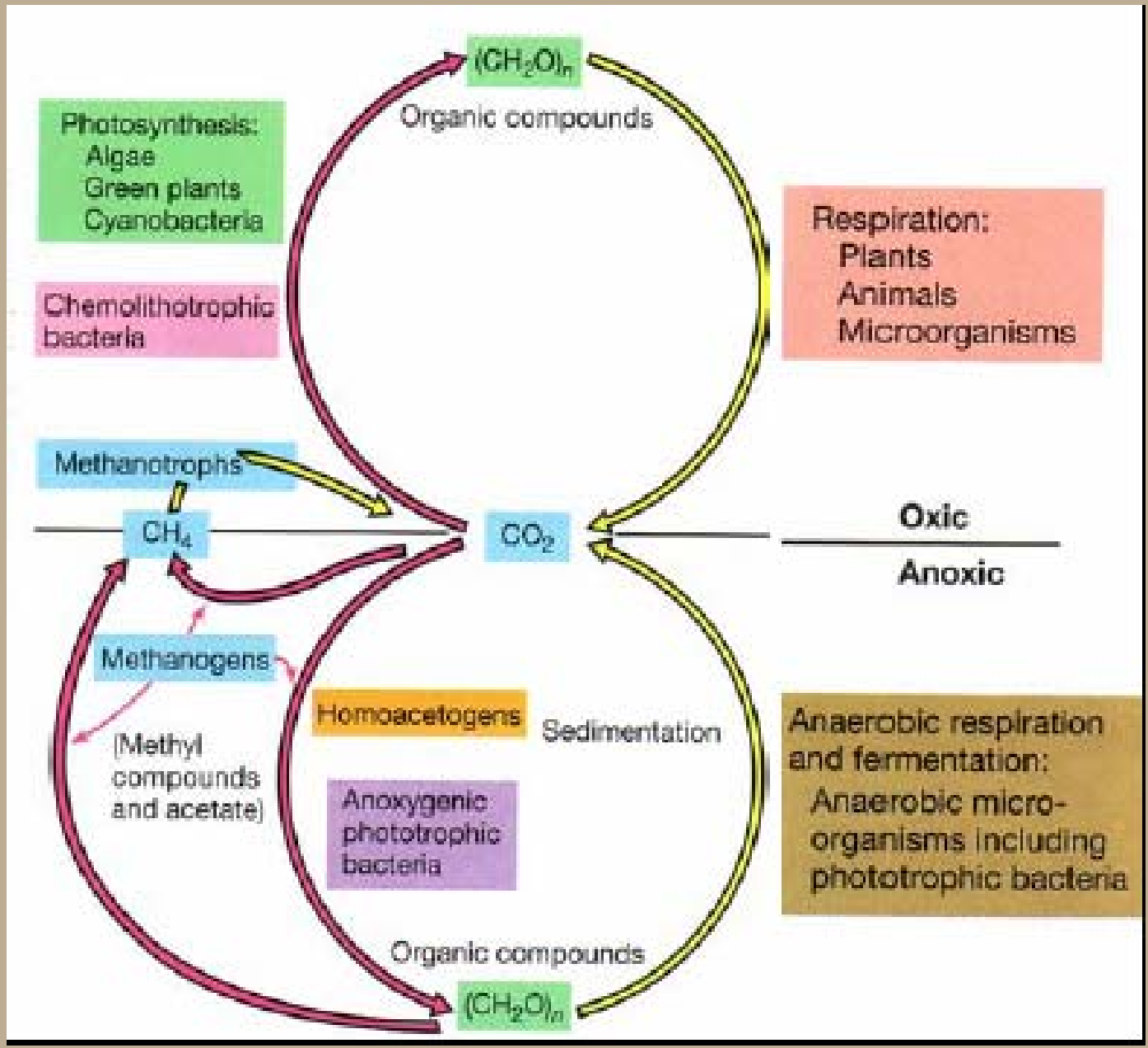
Transformation physico-chimiques et transferts



Flux d'énergie = moteur de la conversion cyclique

Microorganismes → mobilisent, transforment, précipitent

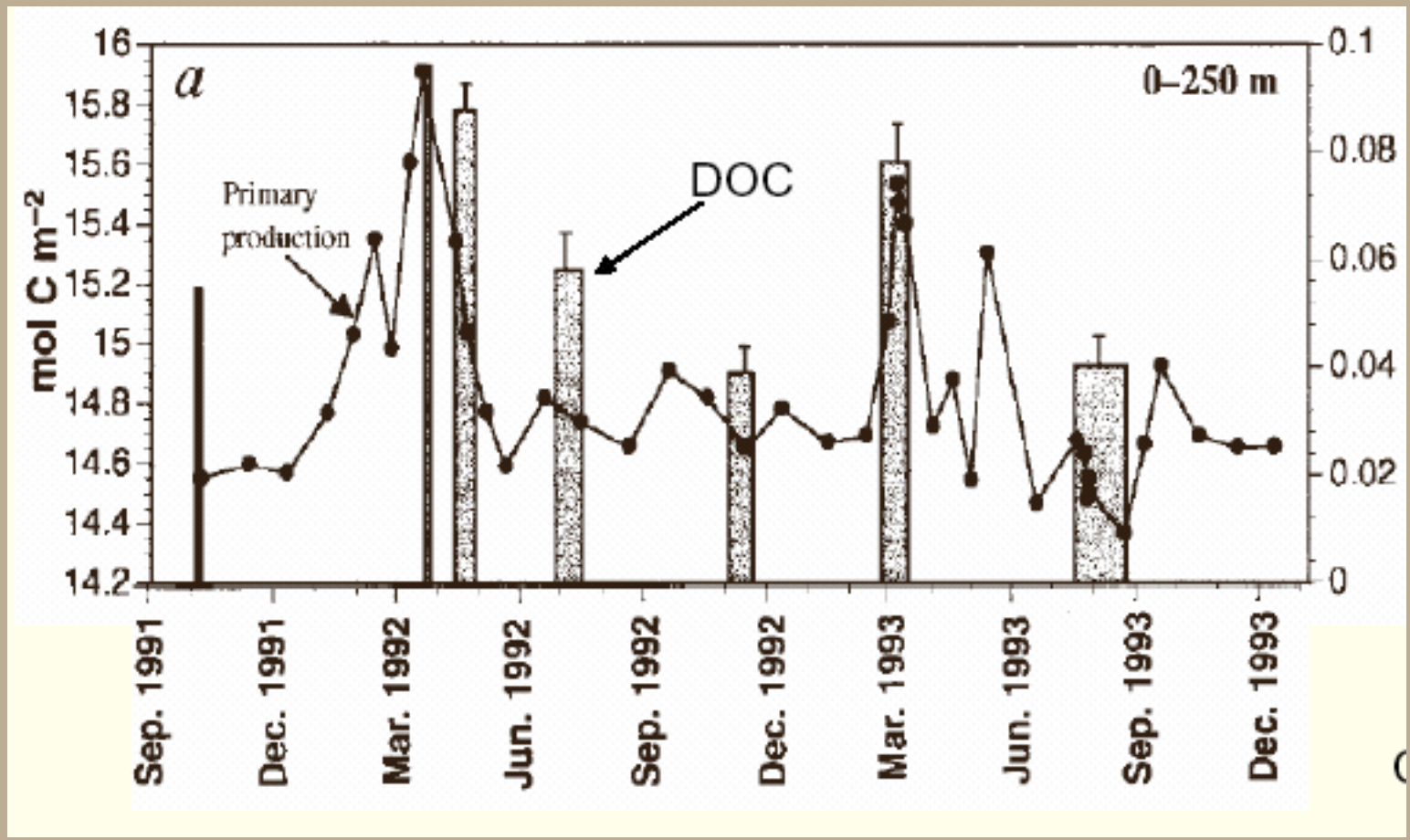
1- CARBONE


$(CH_2O)_n$
Organic compounds
Photosynthesis:
Algae
Green plants
Cyanobacteria
Chemolithotrophic bacteria
Respiration:
Plants
Animals
Microorganisms
Methanotrophs
CH_4
CO_2
Oxic
Anoxic
Methanogens
(Methyl compounds and acetate)
Homoacetogens
Sedimentation
Anoxygenic phototrophic bacteria
Anaerobic respiration and fermentation:
Anaerobic micro-organisms including phototrophic bacteria
Organic compounds
$(CH_2O)_n$

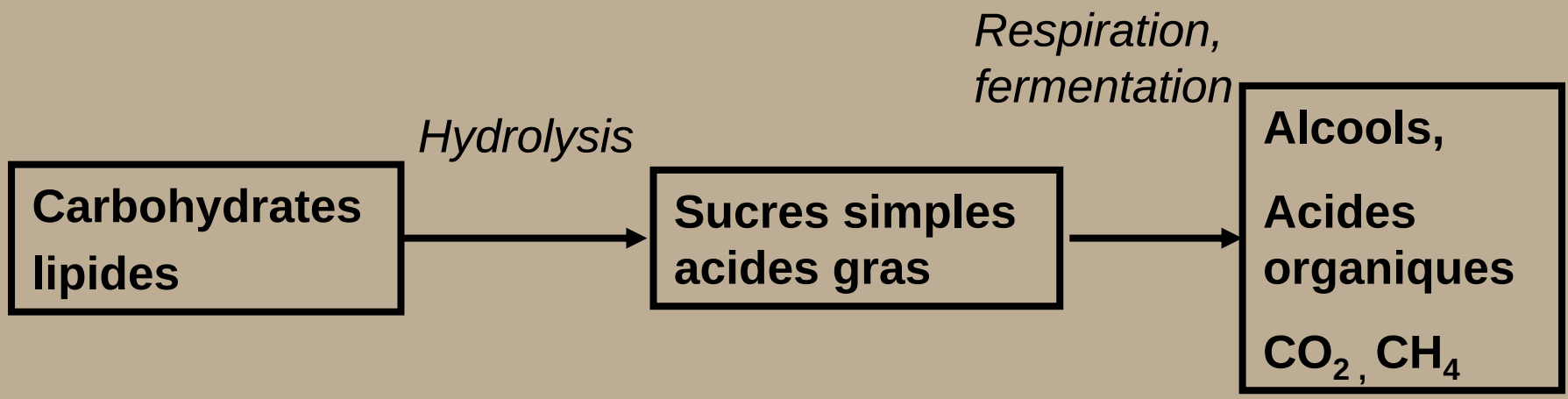
Autotrophes

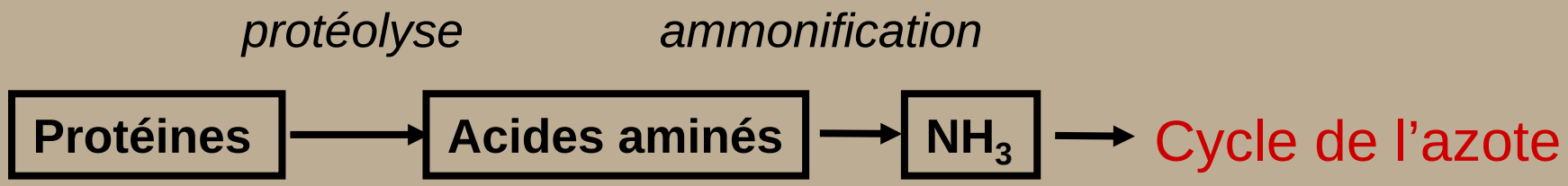
fixation *synthèse*

CO_2 → **Sucres simples acides gras Acides aminés** → **Carbohydrates Lipides protéines**



Hétérotrophes





Matière organique = COP 10% + COD 90%

dégradation → Benthos (lacs et rivières)

dégradation → Pelagos (lacs)

Bactéries et champignons

Facteurs

→ Géomorphologie

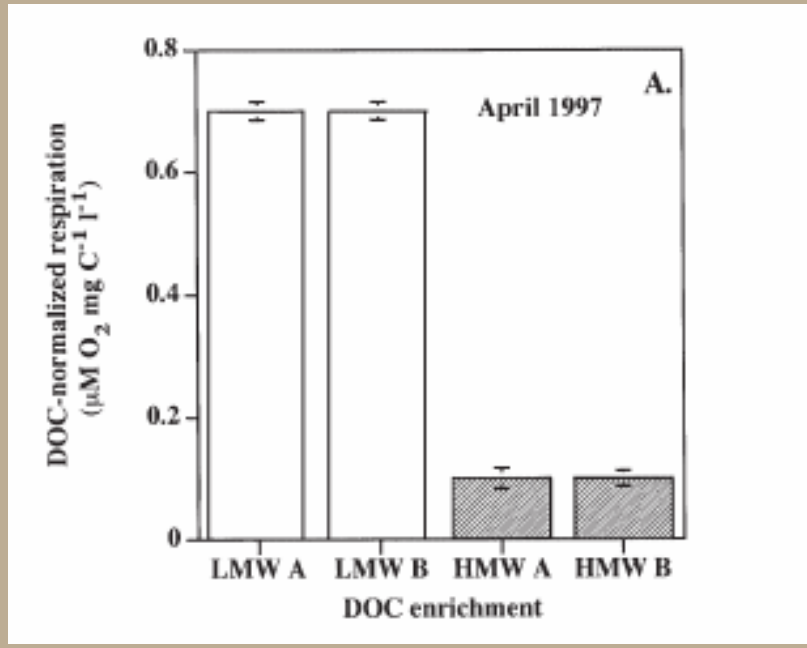
→ type de matière organique

→ Température, O_2, …

Matière organique labile

Carbohydrates, protéines, lipides, pigments, faible PM

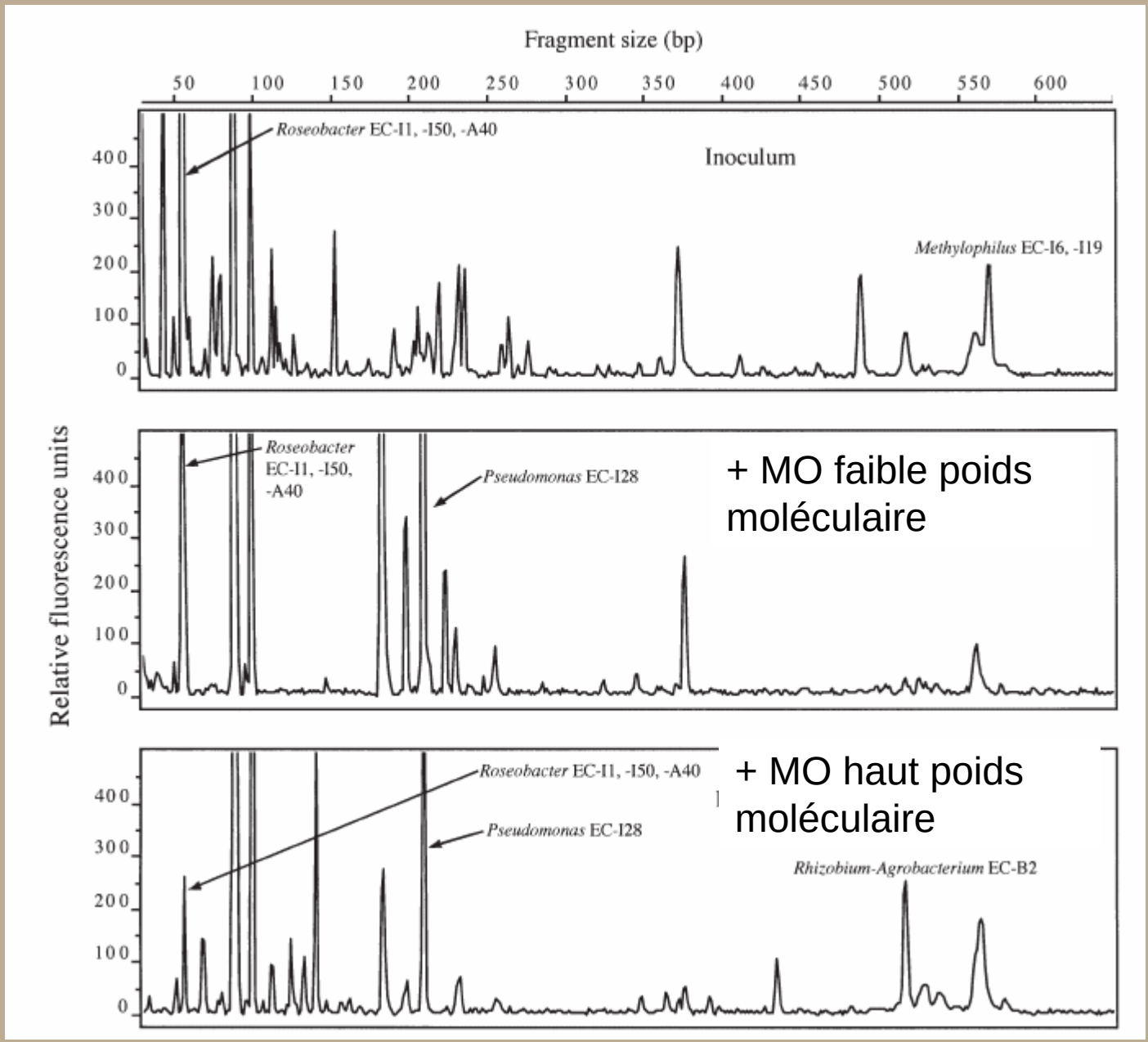
⟶ recyclage rapide, concentration faible



Matière organique réfractaire = 80%

Acides humiques, acides fulviques, haut PM

perte = photolyse, décomposition microbienne, agrégation, sédimentation, déverse

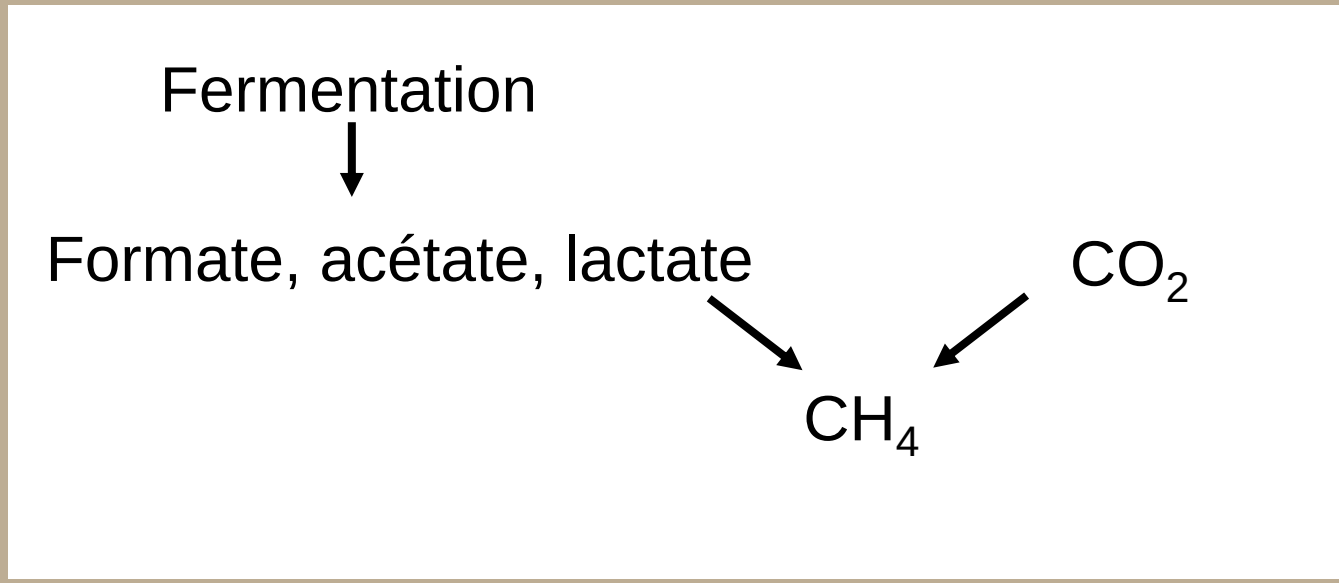


T-RFLP

Covert & Moran 2001

Méthanogènes

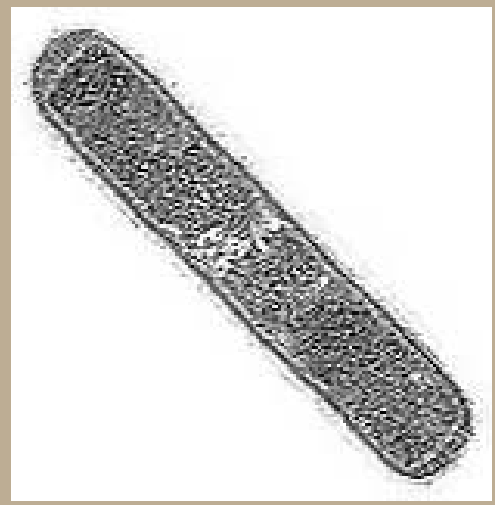
Hétérotrophes et autotrophes



Euryarcheota

Chémoautotrophe

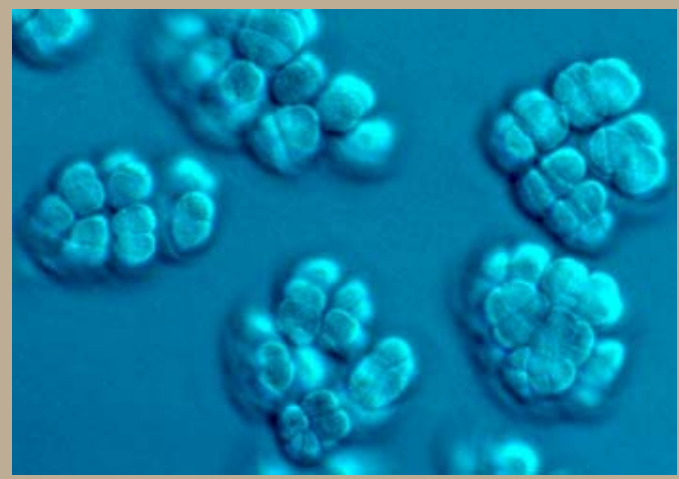
Ex. Methanothermus



$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$

Hétérotrophe = acétotrophiques ou acéticlastique

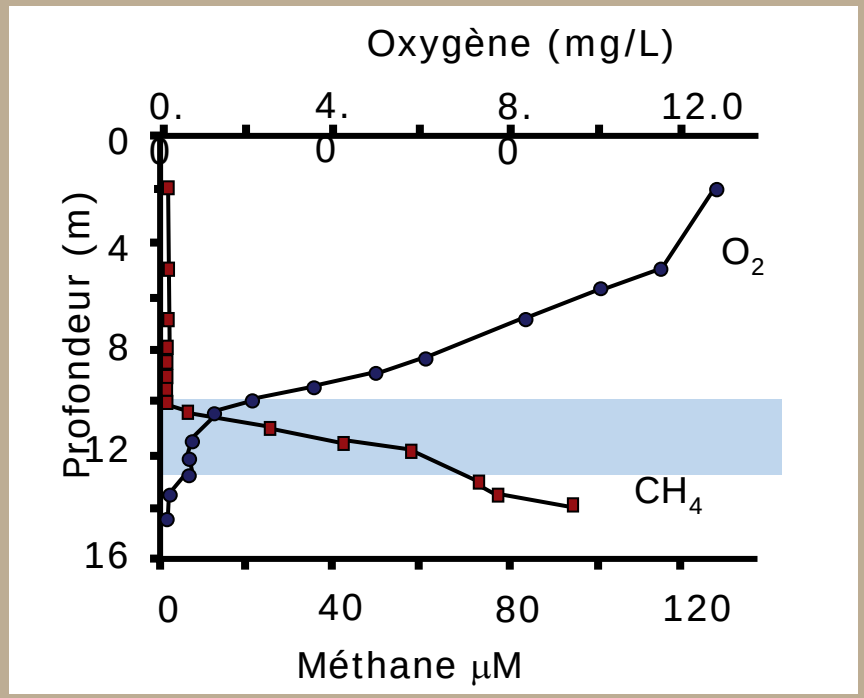
Acétate (fermentation) ⟶ accepteur et donneur d'e-



$CH_3COOH \longrightarrow CH_4 + CO_2$

Methanosarcina & Methanosaeta

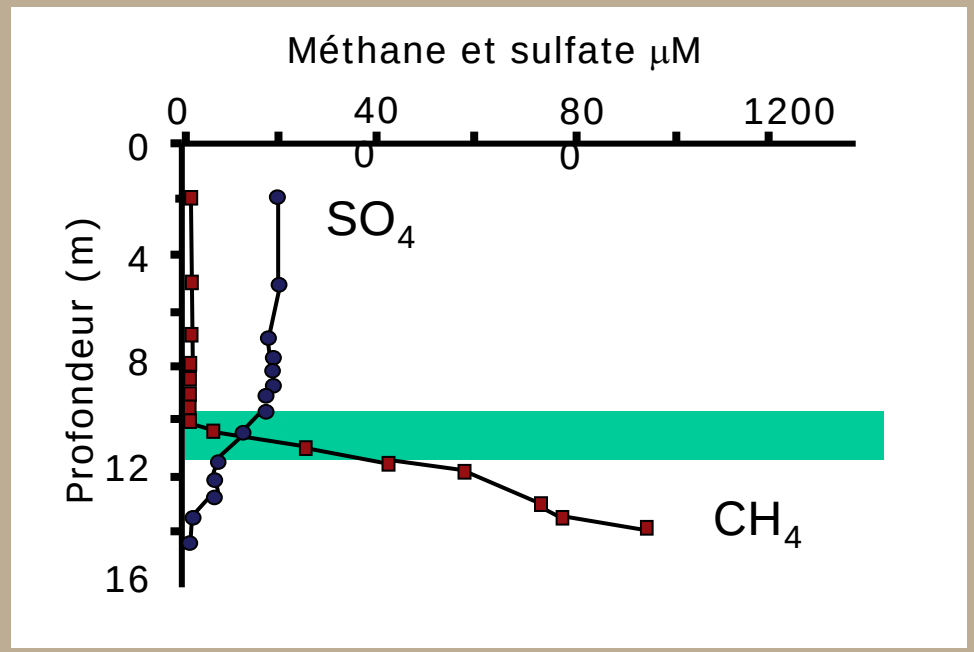
Méthanotrophes



Bactéries

Interface

oxique-anoxique



Archées

Zone de transition

Méthane-sulfate

Oxidation + O_2

méthanol *formaldehyde* *formate*

$CH_4 \longrightarrow CH_3OH \longrightarrow HCHO \longrightarrow HCOOH \longrightarrow CO_2 + H_2O$

Monooxygénase

$CH_4 + 0.5\ O_2 \longrightarrow CH_3OH$

Catalyse aussi NH_3 oxidation

Particulaire pMMO

Soluble sMMO (type II)

α- et γ-Protéobactéries

Gènes *pmoA et mmoB*

↓

Détection des méthanotrophes

Oxidation anaérobie

Archaea = ANMEs (Méthanosarcinales)

Consortium avec des **Bactéries** SRB (Désulfosarcinales)

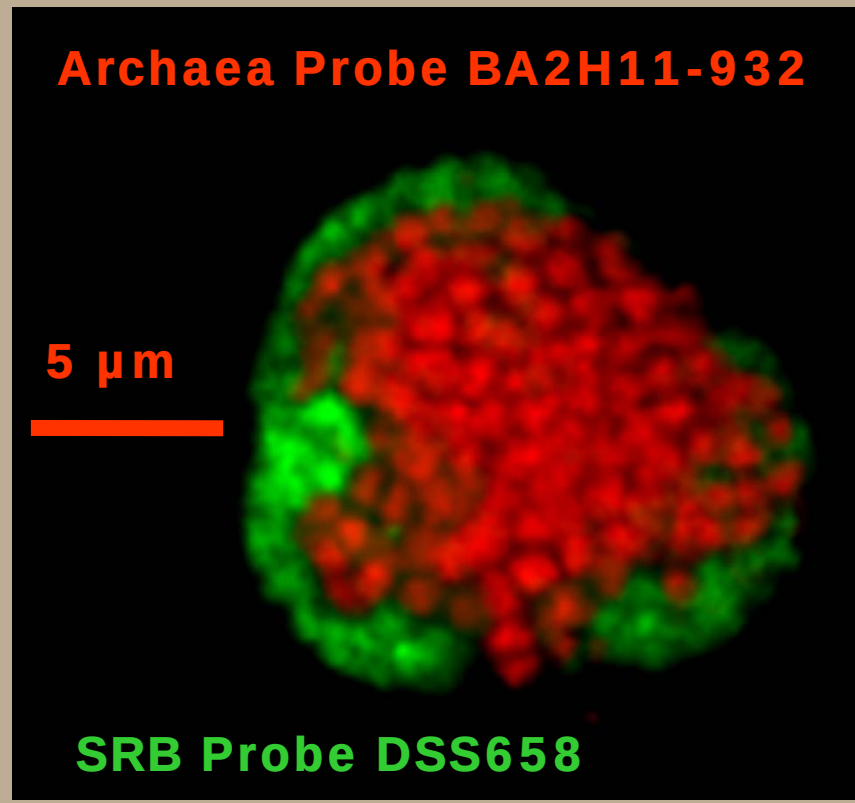
méthanogènes

$CH_4 + H_2O \longrightarrow CO_2 + 4H_2$

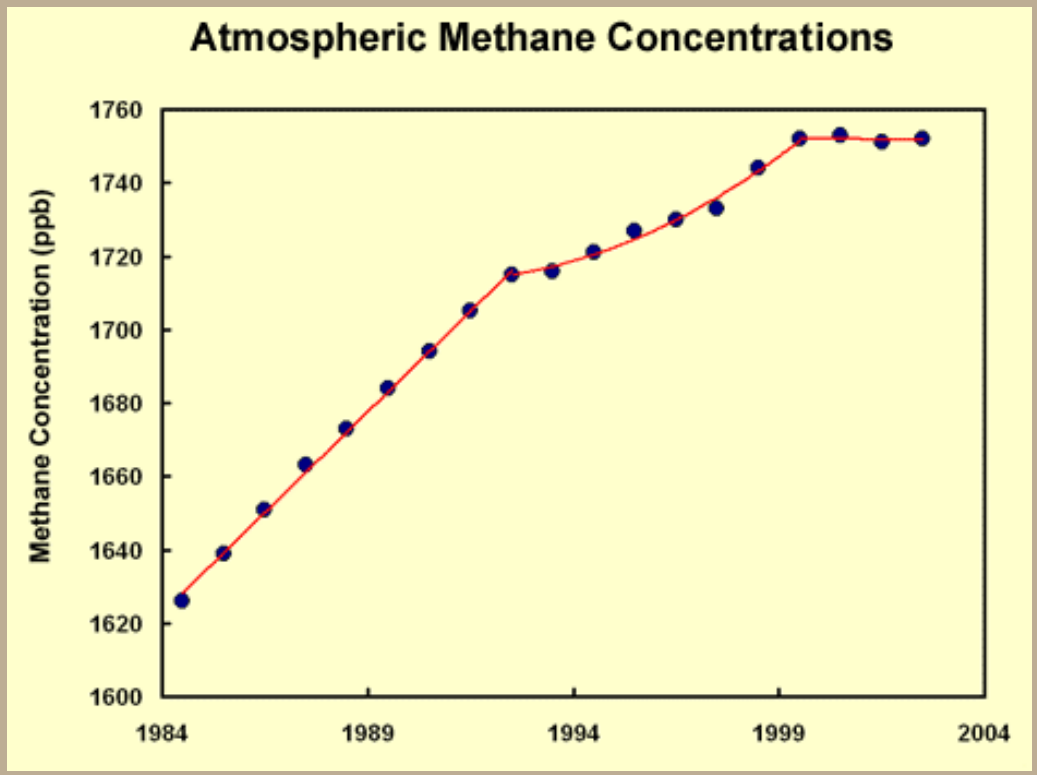
Méthanogénèse inverse

SRB

$HSO_4^{2-} + 4H_2 \longrightarrow HS^- + 4H_2O$



Morteratschgletscher



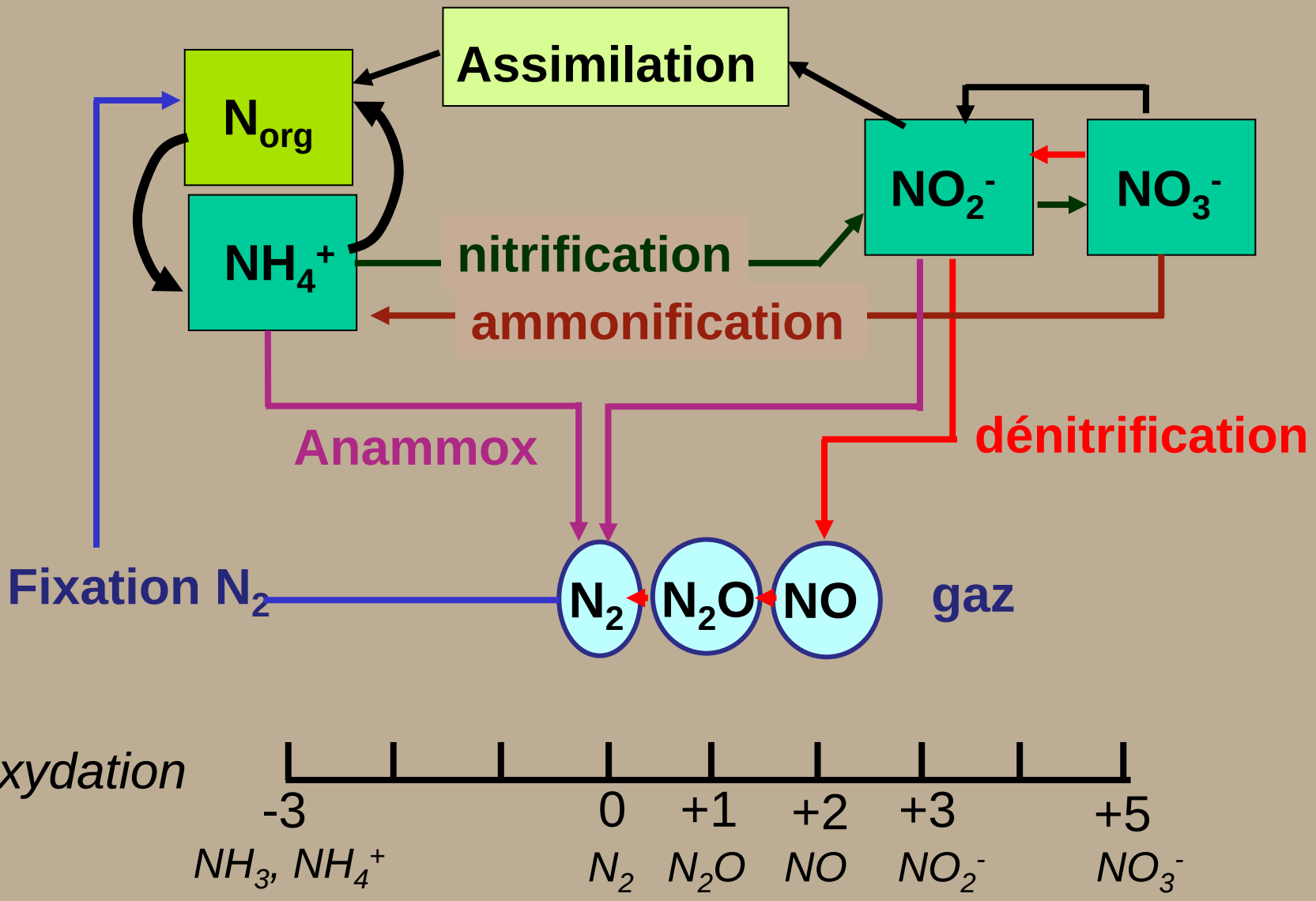
Depuis 1750

+ 150% =

850 ppb à 1.7 ppm

Depuis 1999
ralentissement =
+1%/an

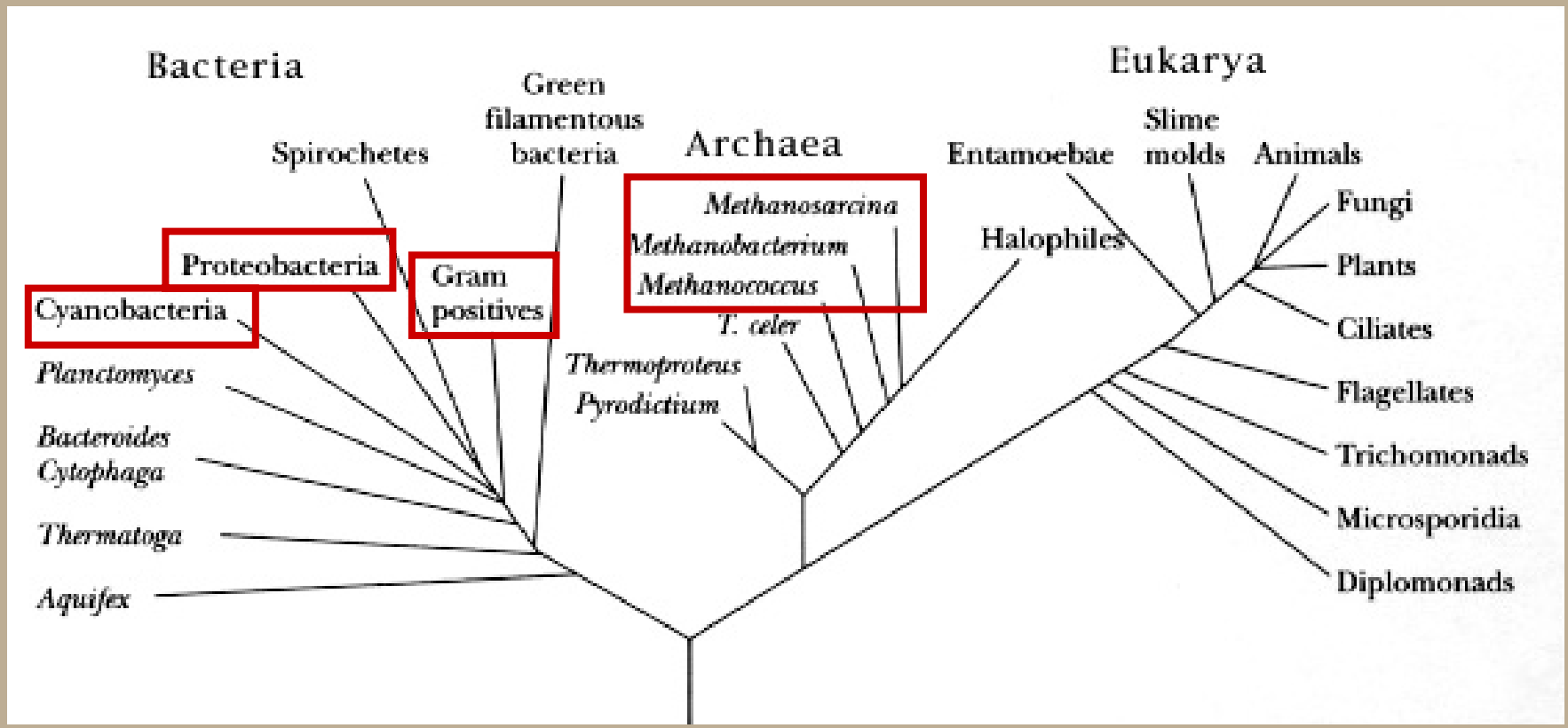
2- AZOTE


Assimilation
N_{org}
NH_4^+
NO_2^-
NO_3^-
nitrification
ammonification
Anammox
dénitrification
Fixation N_2
N_2
N_2O
NO
gaz
oxydation
-3
0
+1
+2
+3
+5
NH_3, NH_4^+
N_2
N_2O
NO
NO_2^-
NO_3^-

Diazotrophie = fixation de N_2 *Dinitrogénase*

$N_2 + 2H^+ \longrightarrow$ diimide $+ 2H^+ \longrightarrow$ hydrazine$+2H^+ \longrightarrow 2NH_3 + H_2$

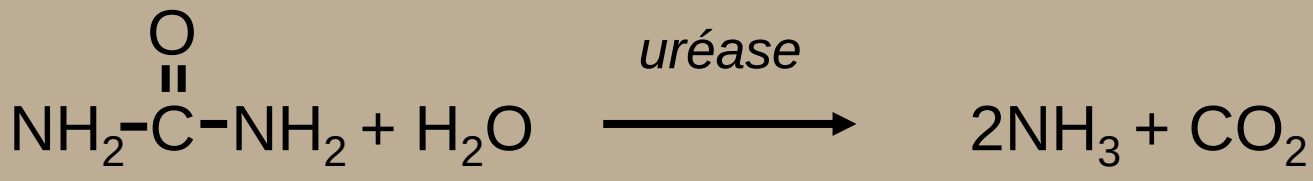
Triple liaison

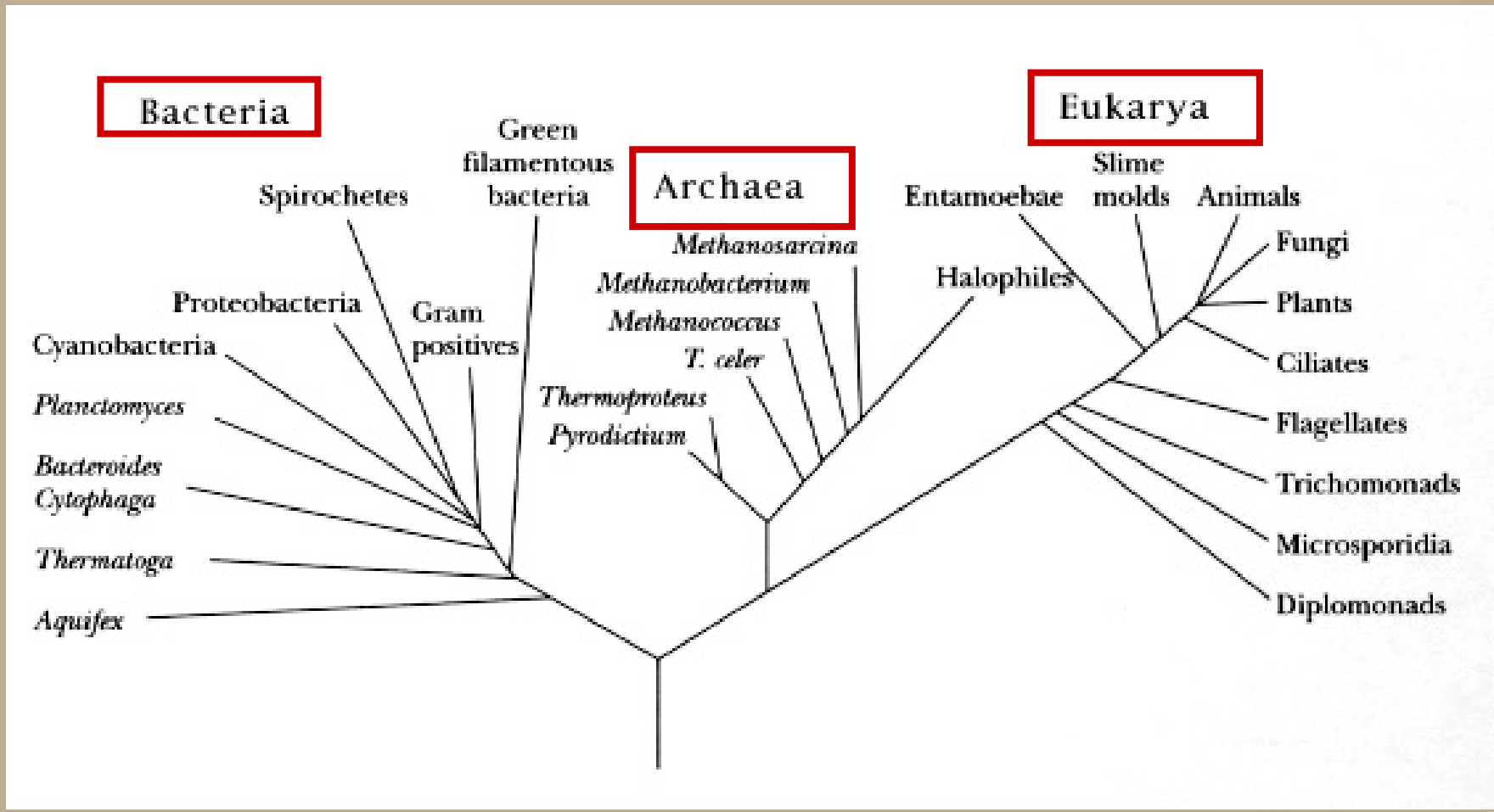


réduction

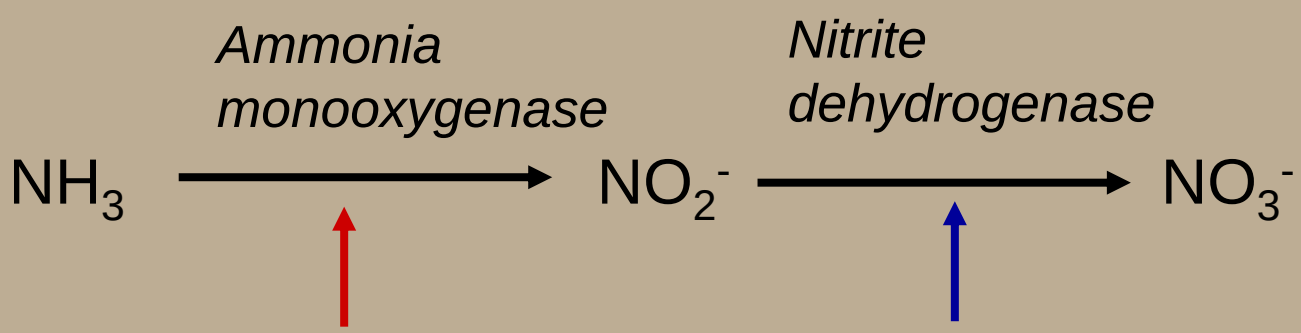
acétylène $\longrightarrow$ éthylène $\longrightarrow$ GC

Ammonification





Nitrification



Ammonium Oxidizing Bacteria

nitrosante

***Nitroso**monas*, ***Nitroso**lobus*,
***Nitroso**spira*, ***Nitroso**pumilus*

β et γ- Protébactéries
Crenarchaeota

Nitrite Oxidizing Bacteria

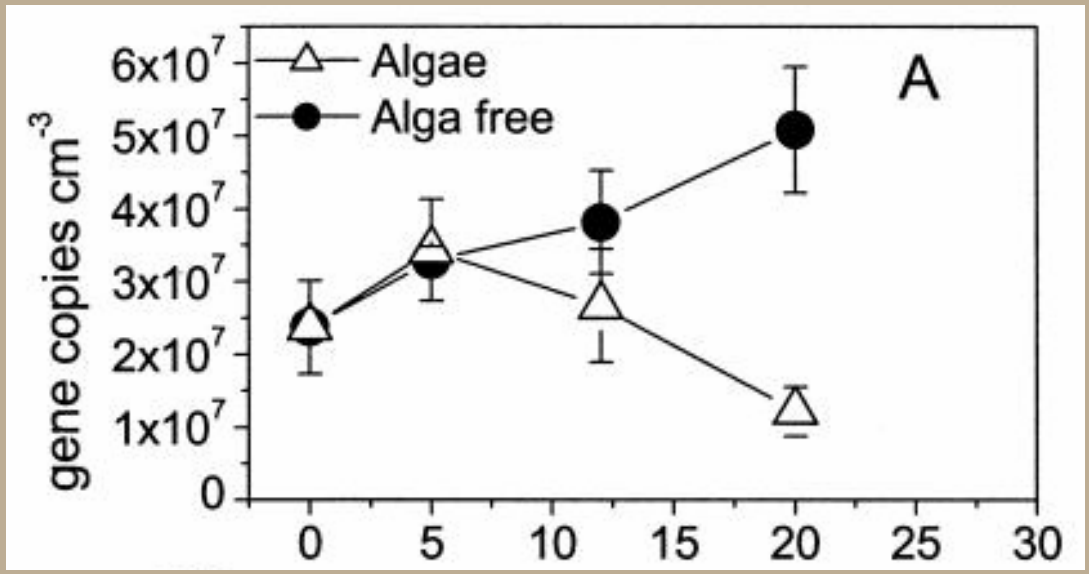
nitratante

***Nitro**bacter*, ***Nitro**spira*,
***Nitro**spina*, ***Nitro**coccus*

α et γ -Protéobactéries

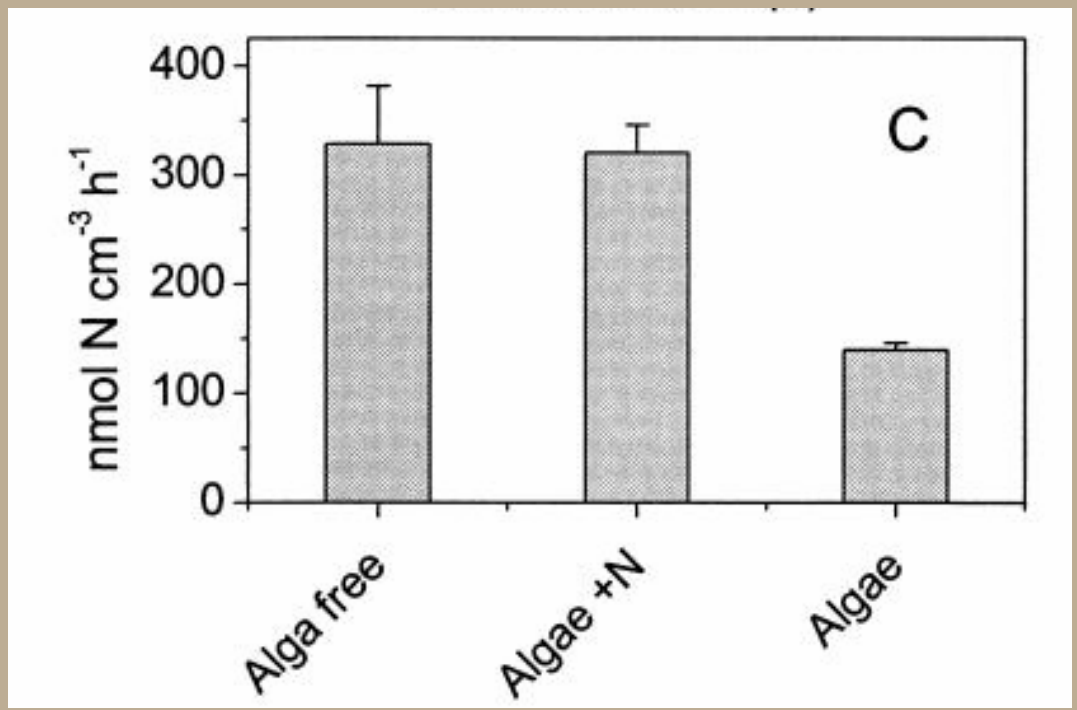
Autotrophes : fixation du CO_2

Compétition avec les algues



amo (PCR quantitative)

Quantité d'AOB



Risgaard-Petersen et al. 2004

Dénitrification

Réduction dissimilative anaérobie

NO_3^-

↓ *Nitrate reductase* — *Nar*

NO_2^-

↓ *Nitrite reductase* — *Nir K et S*

NO

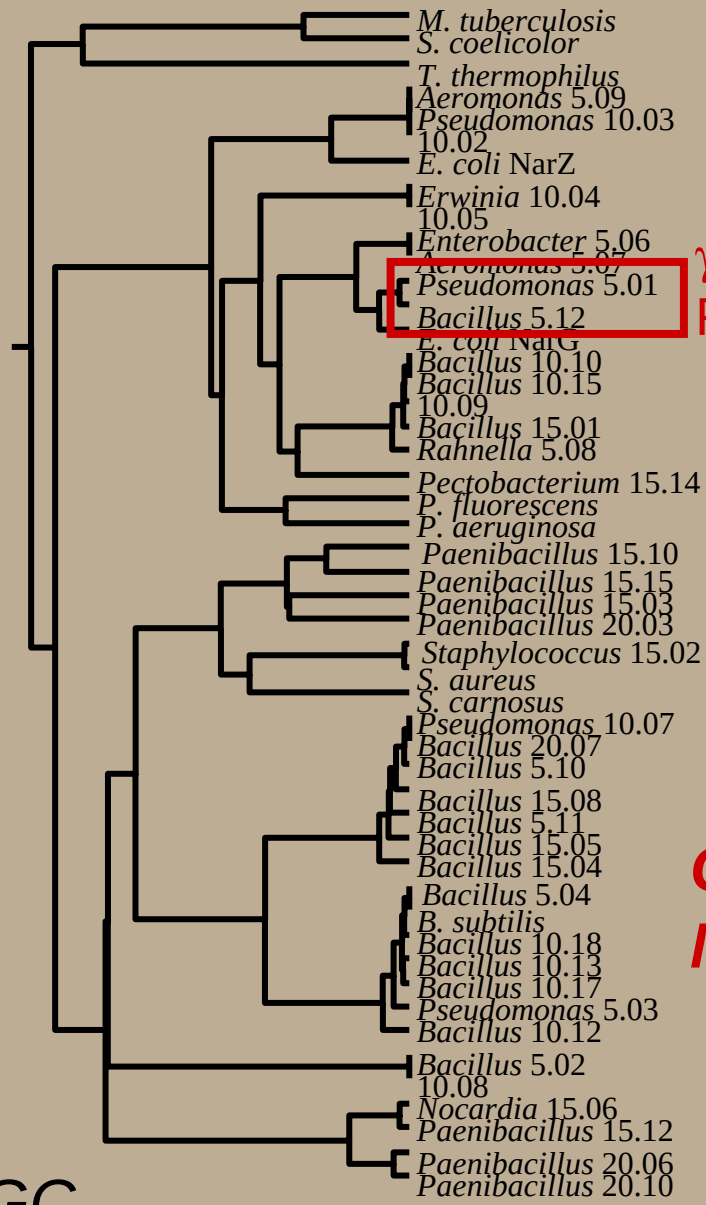
↓ *Nitric oxide reductase*

N_2O

✕ ↓ *Nitrous oxide reductase* — *Noz*

N_2

✕ *Acétylène* → N_2O → *GC*



Réduction dissimilative des nitrates

Bacillus, Pseudomonas, campylobacter, Citrobacter, Klebsiella, Clostridium, Desulfovibrio

Peu ATP généré

→ Détoxification NO_2^-?réoxydation NADH?

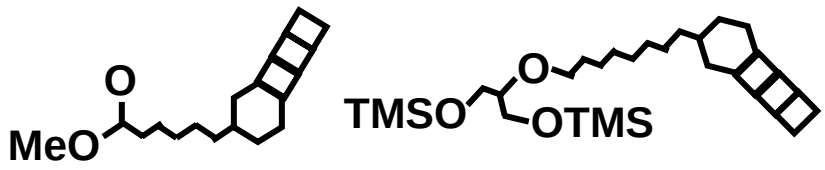
$$\mathbf{NO_3^- + 10H^+ + 8e^- \longrightarrow NH_4^+ + 3\,H_2O}$$

Environnements riches en C, peu de NO_3^-

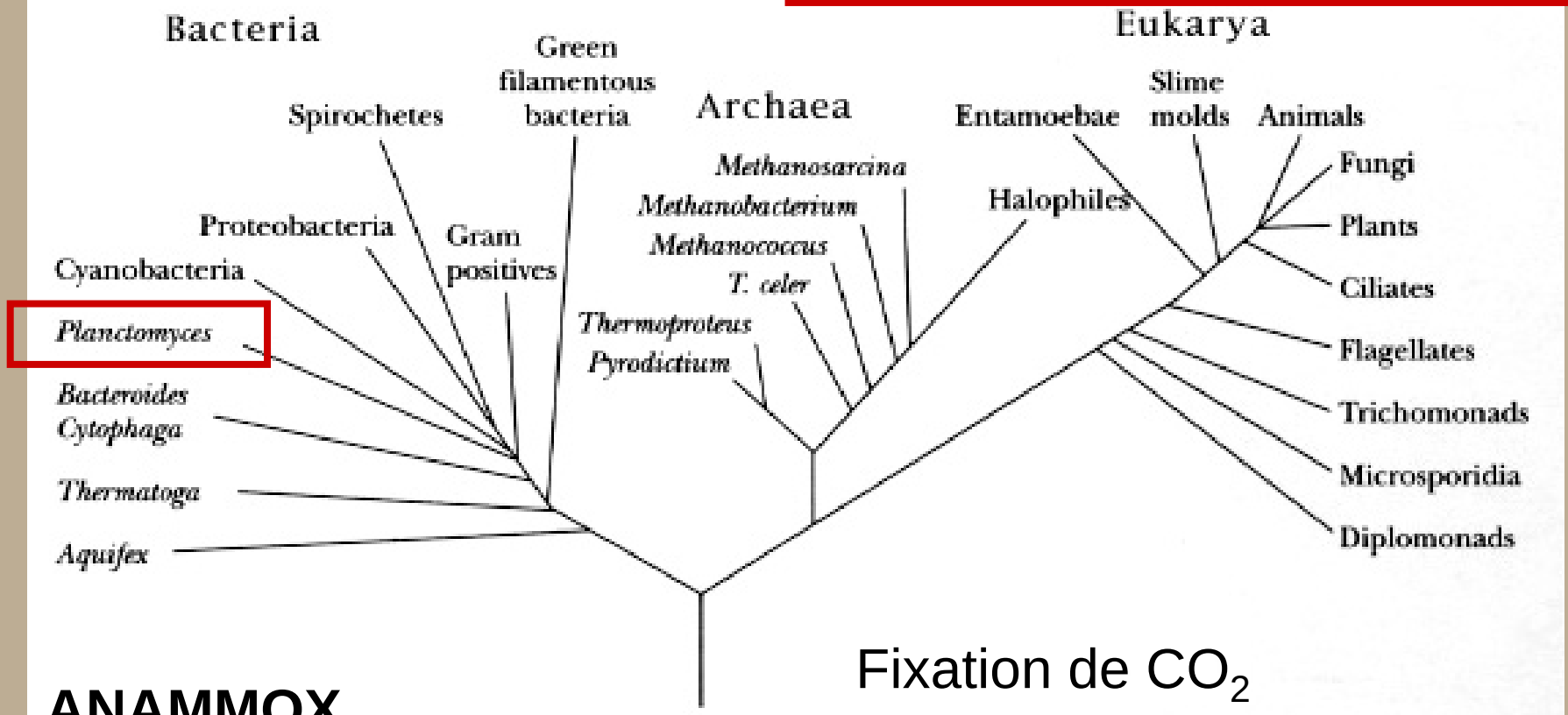
→ Rumen, sédiments anoxiques, fermes d'élevage de poisson

Oxidation anaérobique de l'ammonium

$NO_2^- + NH_3 \longrightarrow 2N_2$

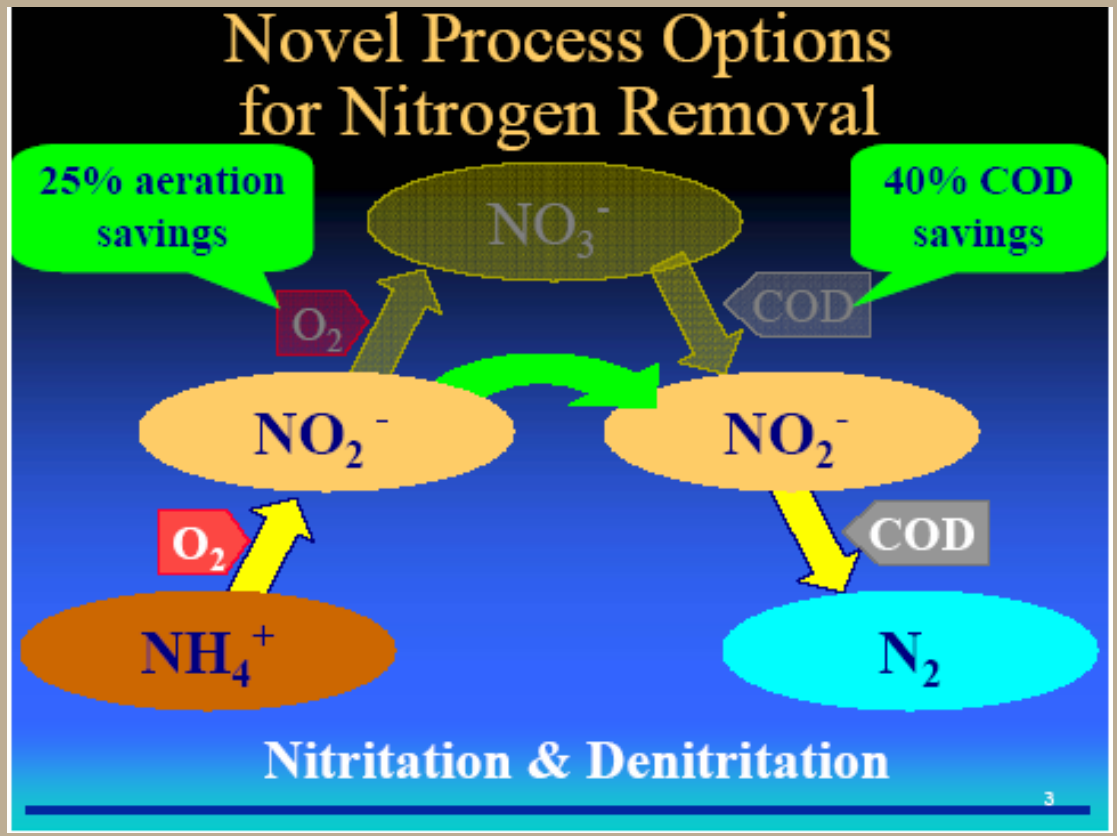


ladderanes $\delta^{13}C \sim -70\%°$



ANAMMOX

Fixation de CO_2



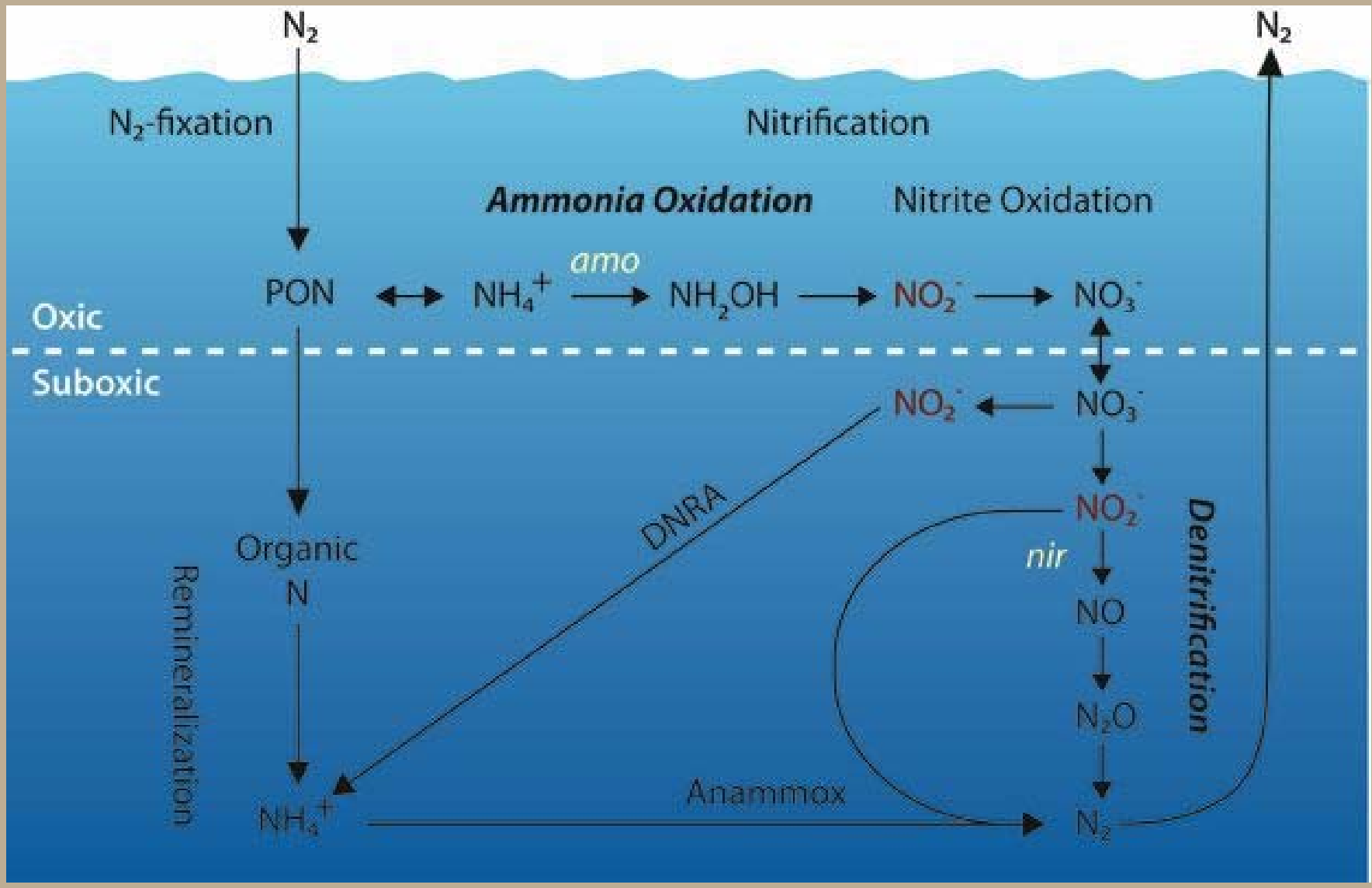
- Sharon-anammox
- CANON

Coût 0.75 vs 2-5 euros/Kg N

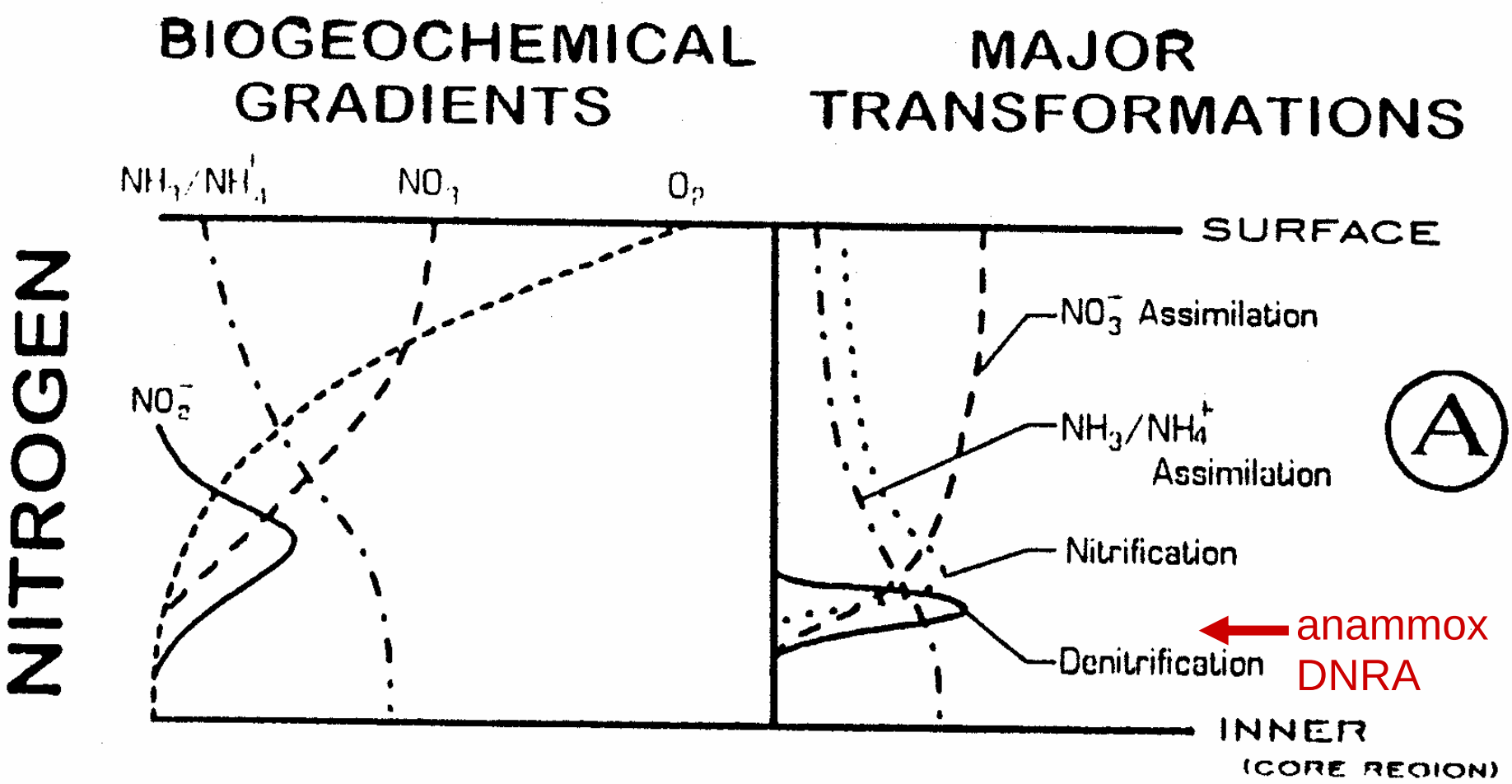
Boues activees enrichies en 100 jours

Rétention de biomasse (granules)

Répartition



Répartition



FLUX de GAZ

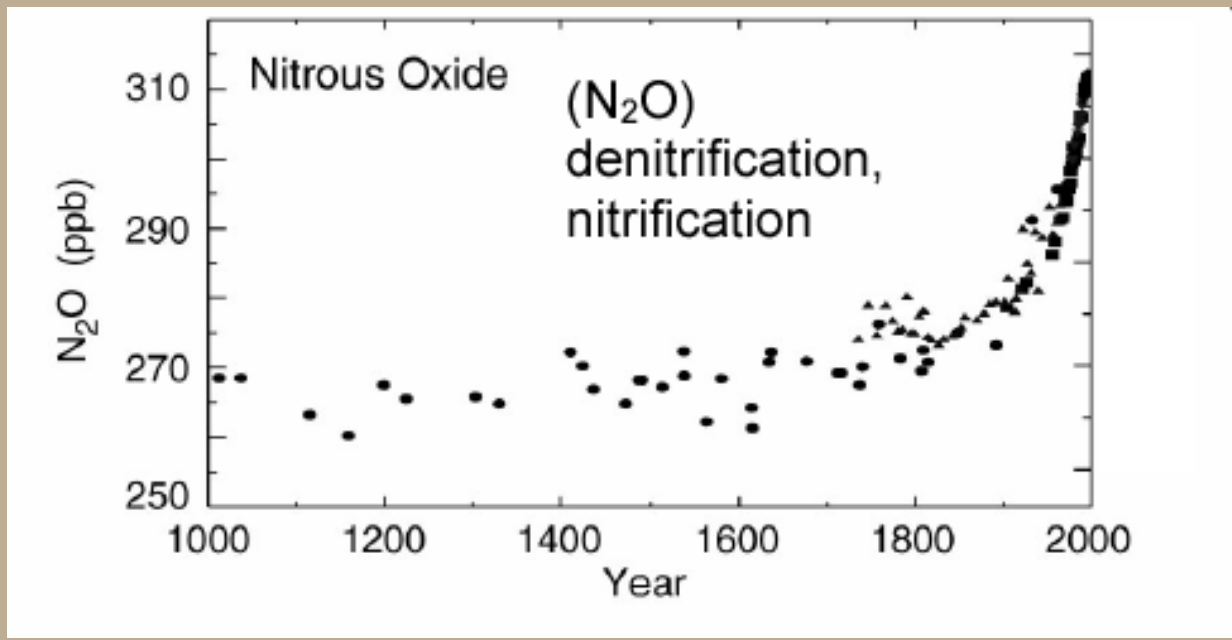
NO_x, N_2O, NH_3 → **atm** → Pluies acides

N_2O → Gaz à effet de serre

310x > CO_2

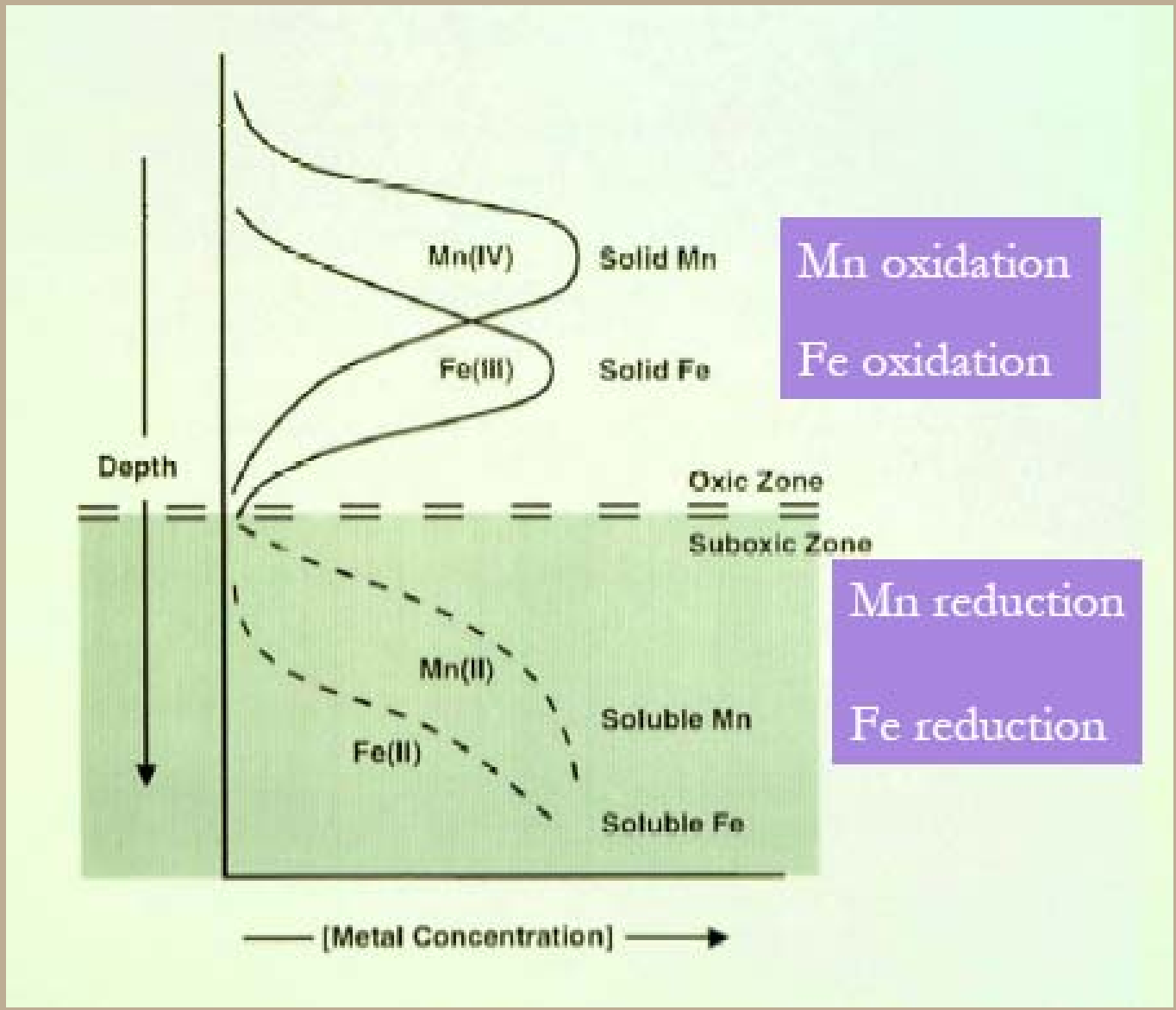
N_2O + NO → destruction de la couche d'O_3

Apports de fertilisants → Concentration atmosphérique

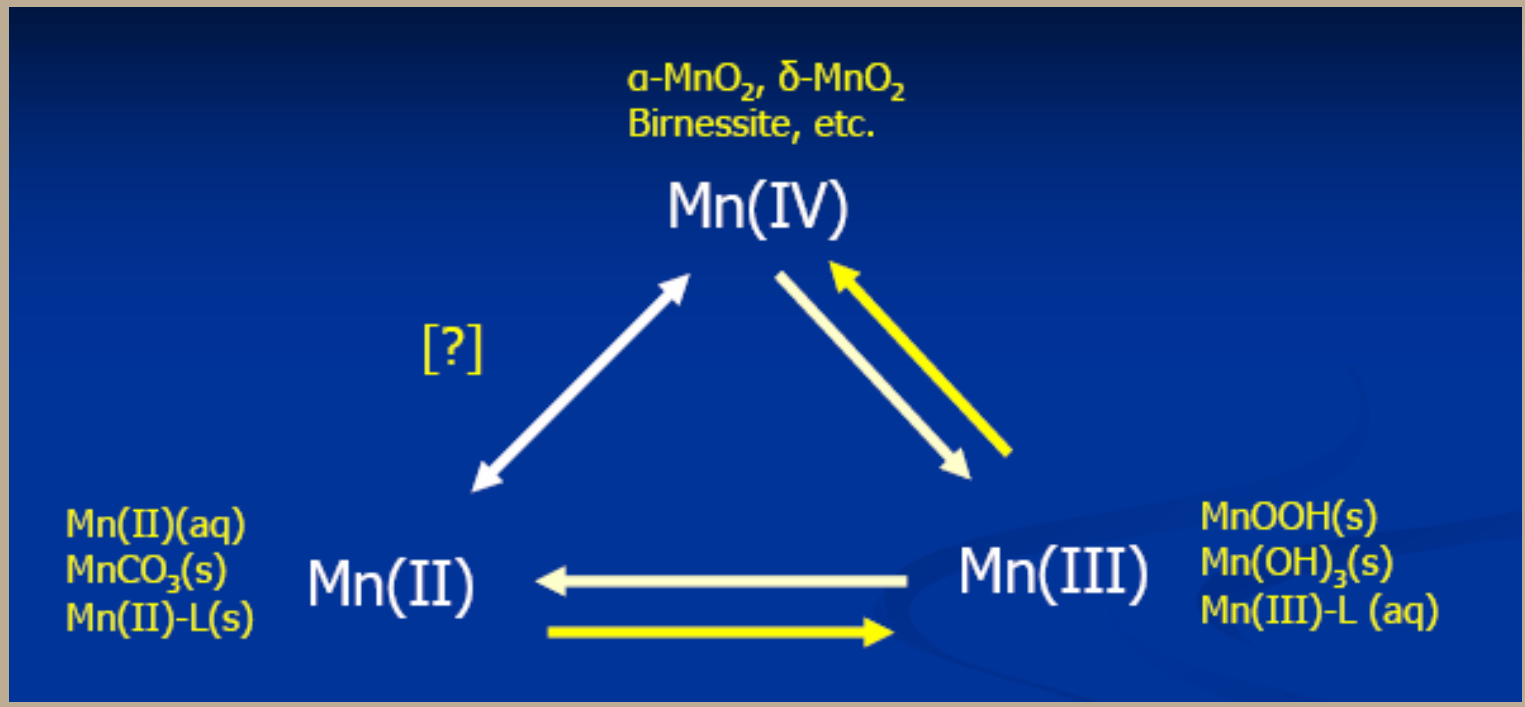


IPCC (2001)

3- Cycles du fer et du manganèse



Manganèse



Réduction du Mn (IV)

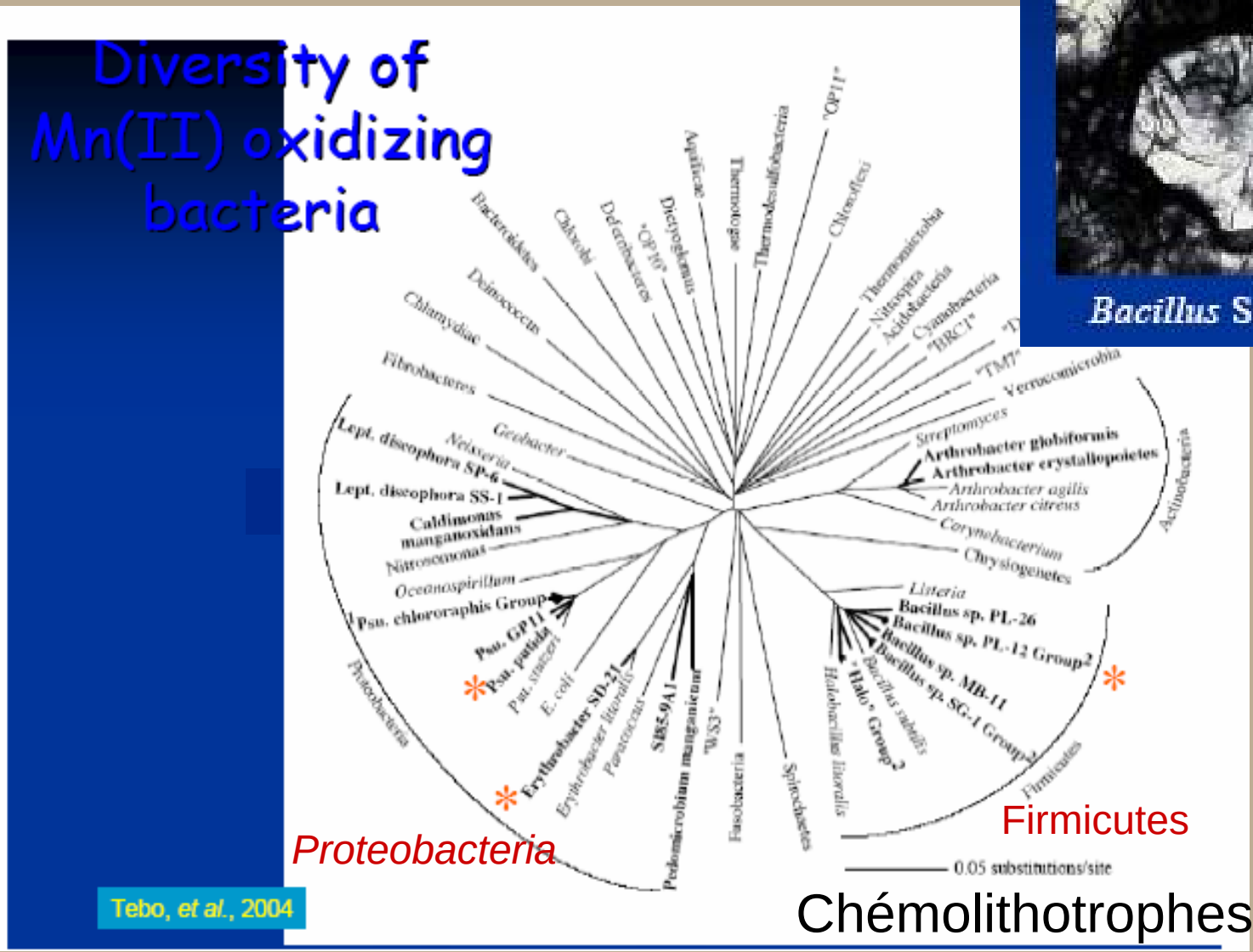
pH faible, Eh faible,

Bactéries?

Oxidation du Mn (II)

pH >9, Eh élevé

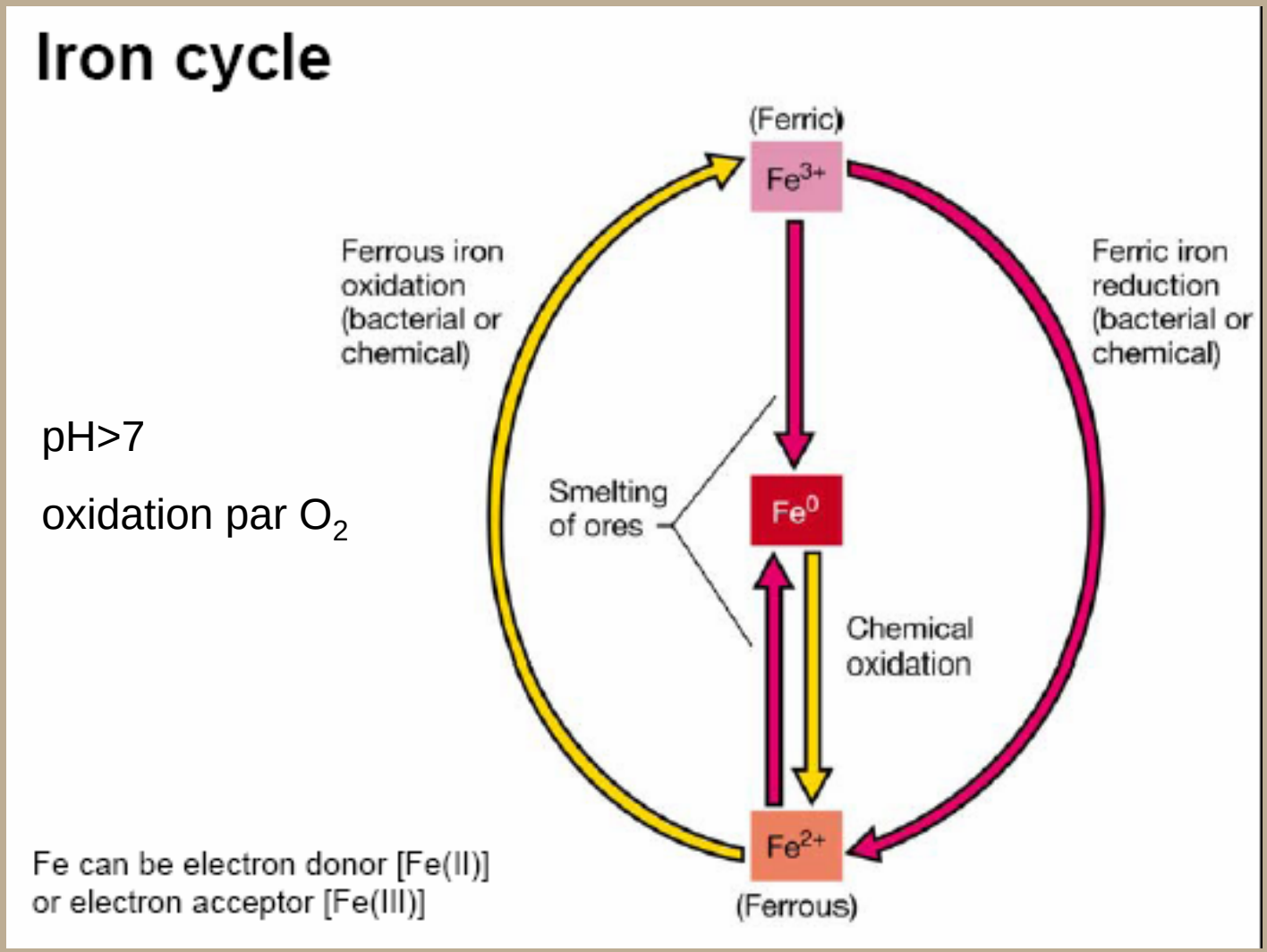
Bactéries hétérotrophes + champignons



Chémolithotrophes???

$$Mn^{2+} + 0.5O_2 + H_2O \longrightarrow MnO_2 + 2H^+$$

FER Nature ⟶ Fe (III) et Fe (II)



pH>7

oxidation par O_2

Oxidation du fer (II)

Neutrophilique et acidophilique (aérobique)

$$4FeCO_3 + O_2 + 6H_2O \longrightarrow 4Fe(OH)_3 + 4CO_2$$

Thiobacillus, Leptospirillum, Gallionella, Sulfolobus spp.

Phototrophique et dépendante des nitrates (anaérobique)

$$HCO_3^- + 4Fe_2^+ + 10H_2O + \text{photons} \longrightarrow CH2O + 4Fe(OH)_3 + 7H^+$$

$$10FeCO_3 + 2NO_3^- + 24H_2O \longrightarrow 10Fe(OH)_3 + N_2 + 10HCO_3^- + 18H^+$$

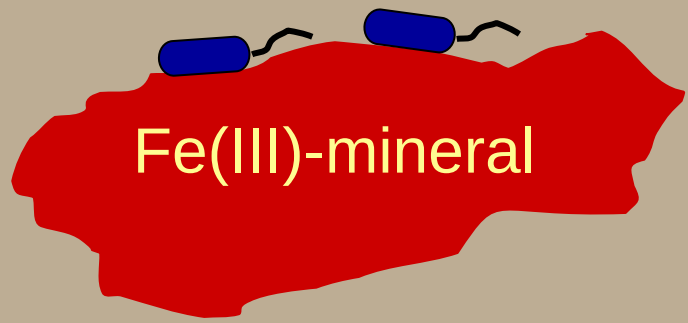
Proches de *Chlorobium* et *Rhodobacter*

Réduction du fer (II)

Respiration anaérobie

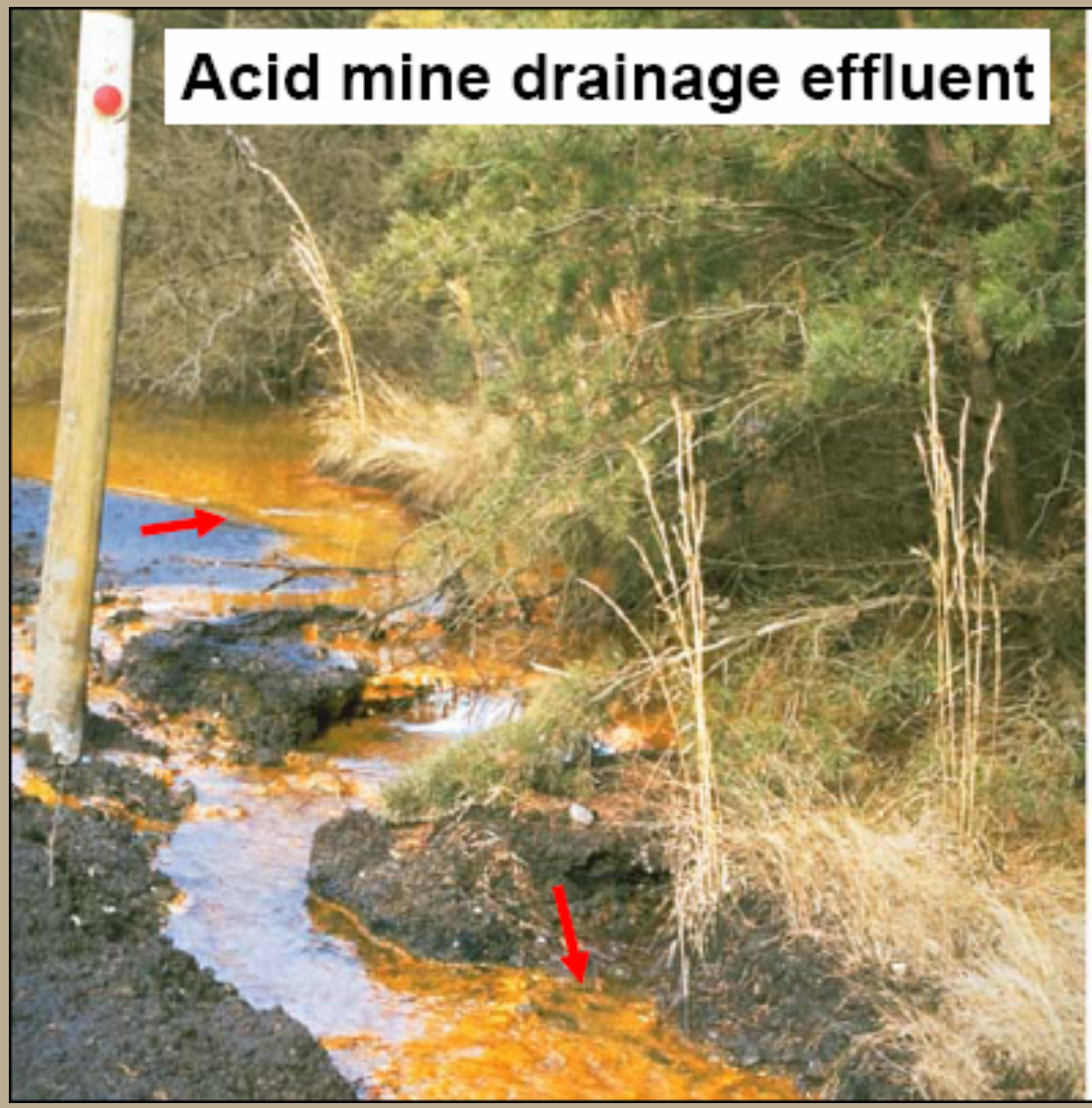
Matière organique + Fe(III) $\longrightarrow$ CO_2 + Fe^{2+}

Geobacter, Shewanella, Desulfuromonas, Bacillus, Pseudomonas, Proteus, Clostridium



+ Oxidation de la pyrite, formation de magnétite

Mines de charbon



$$\text{Pyrite} + O_2 \rightarrow H_2SO_4 + Fe\ (III)_d$$

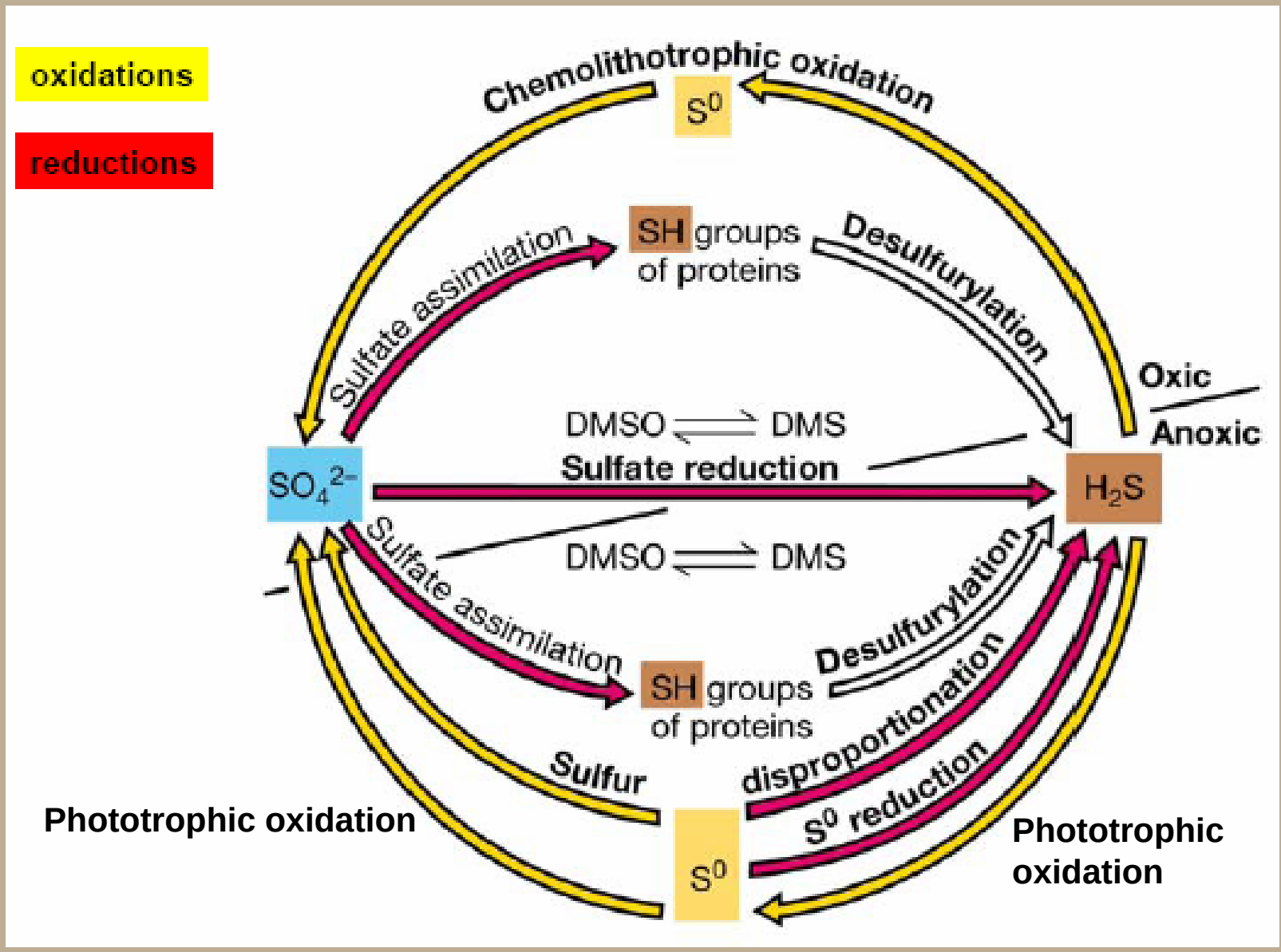
Bacterial oxidation of Fe-sulfides

-> production of sulfuric acid

-> dissolved Fe(III) at acidic pH; precipitates at neutral pH

Pyrite ⟶ roches riches en fer et soufre

4- Cycle du soufre



Oxidation	forme	exemples
-2	S^{2-}	sulfides, mercaptans
0	S^{0}	soufre élémentaire
+2	S_2O_4	hyposulfite
+4	SO_3^{2-}	sulfite
+6	SO_4^{2-}	sulfate

Acides aminés = cystéine, méthionine (-SH)

DMSO → DMS

Désulfuration

Cystéine + H_2O ⟶ serine + H_2S

desulfhydrase

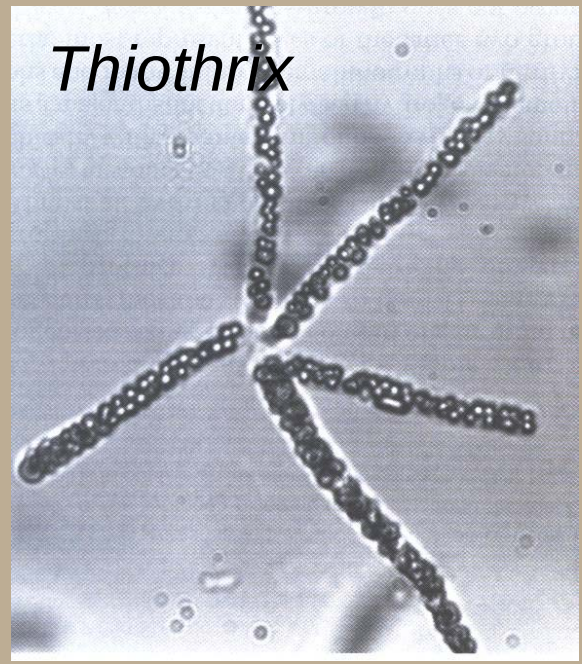
Oxidation aérobie

chémolithotrophes

$$H_2S + 0.5O_2 \longrightarrow S^0 + H_2O$$

Bactéries filamenteuses microaerophiles

Beggiatoa, Thioploca, Thiothrix, Thermothrix



Non acidophiles ⟶ Granules de soufre

Acidophiles pH 2-3

Certains *Thiobacillus* spp. Archées *Sulfolobus*

$$S^0 + 1.5O_2 + H_2O \longrightarrow H_2SO_4$$

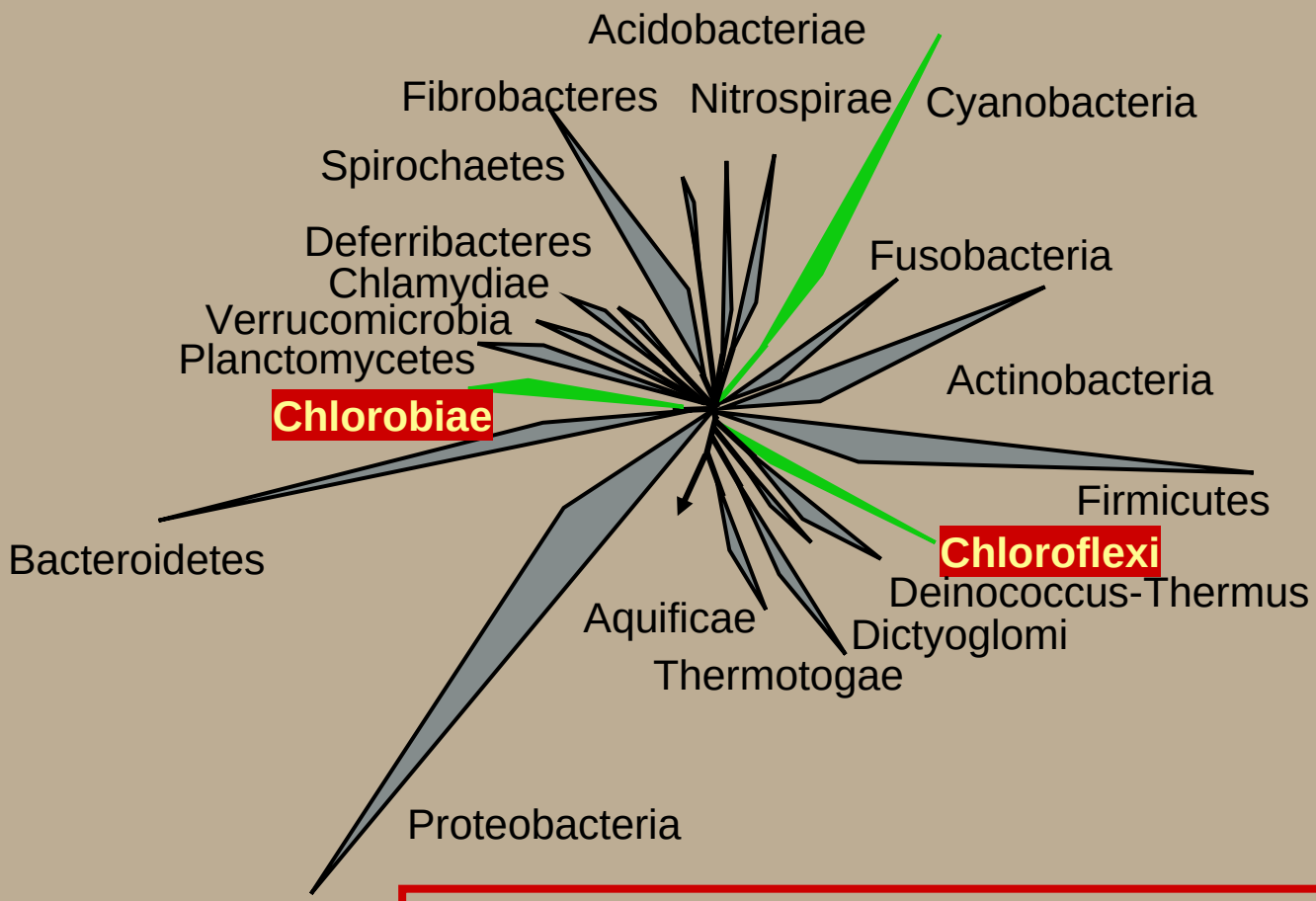
Thiobacillus denitrificans

$$3S^0 + 4NO_3^- \longrightarrow 2N_2 + 3SO_4^{2-}$$

T. Thiooxidans et *T. ferrooxidans* ⟶ activité minière

⟶ Rejets miniers acides

Oxidation anaérobie photolithotrophes



$$H_2S + CO_2 \longrightarrow S^0 + [CH_2O]$$

Cyanobactéries $H_2O + CO_2 \longrightarrow O_2 + [CH_2O]$

Réduction dissimilative (anaérobie)

Fractionnement $^{32}S/^{34}S$ ⟶ H_2S biogène

soufre

$$CH_3COOH + 2H_2O + 4S^0 \longrightarrow 2CO_2 + 4H_2S$$

Desulfuromonas et archées hyperthermophiles

$$H_2 + S^0 \longrightarrow H_2S$$

Archées hyperthermophiles et chémolithotrophes

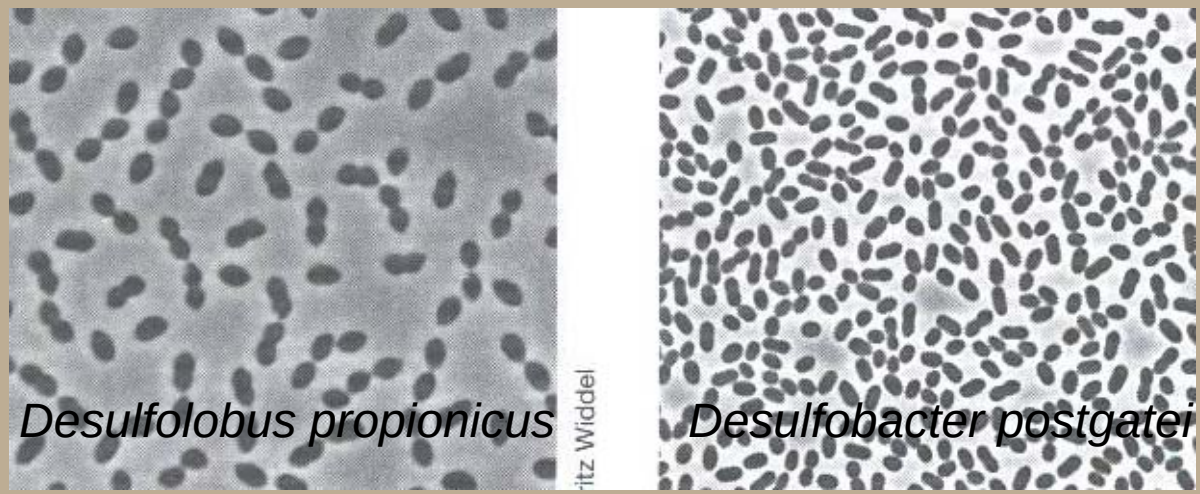
sulfate SRB

$$5H_2 + 2SO_4^{2-} \longrightarrow 2H_2S + 2H_20 + 2OH^-$$

Gram +: *Desulfotomaculum* | hétérotrophes

δ-Protéobactéries

Archaea: *Archaeoglobus* chémolithotrophes



Disproportionation

Absence de CO_2 et O_2

Sorte de fermentation inorganique

Soufre élementaire et thiosulfate

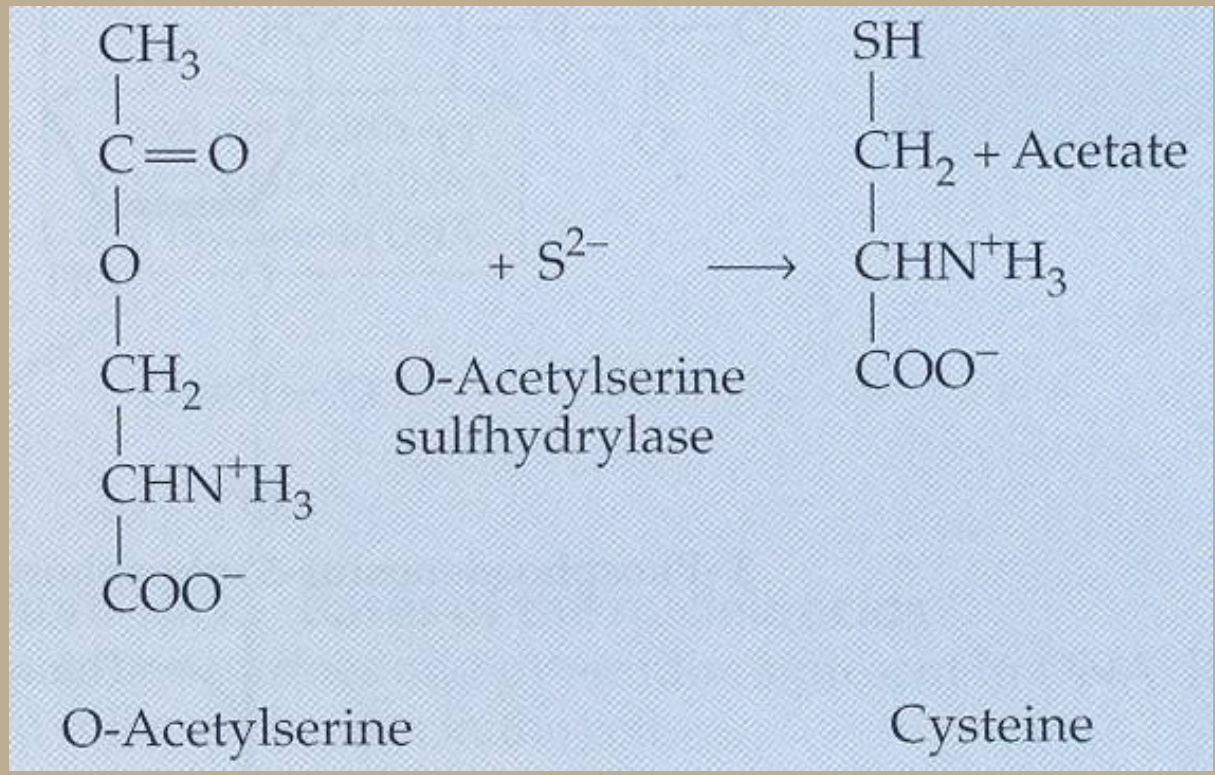
$$S_2O_3^{2-} \longrightarrow H_2S + SO_4^{2-}$$

- Pas de croissance couplée (SRB)
- croissance couplée (en présence de FeOOH, MnO_4)

Important dans les écosystèmes aquatiques

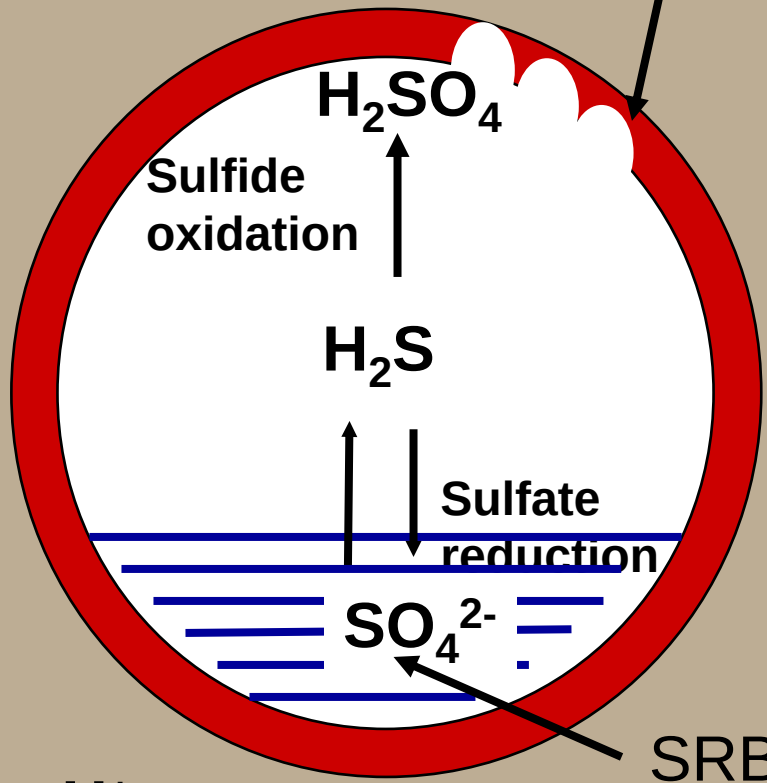
Réduction assimilative

$SO_4^{2-} \longrightarrow S^{2-} \longrightarrow$ biomasse



Canalisation d'égouts

Corrosion du béton, du fer, acier



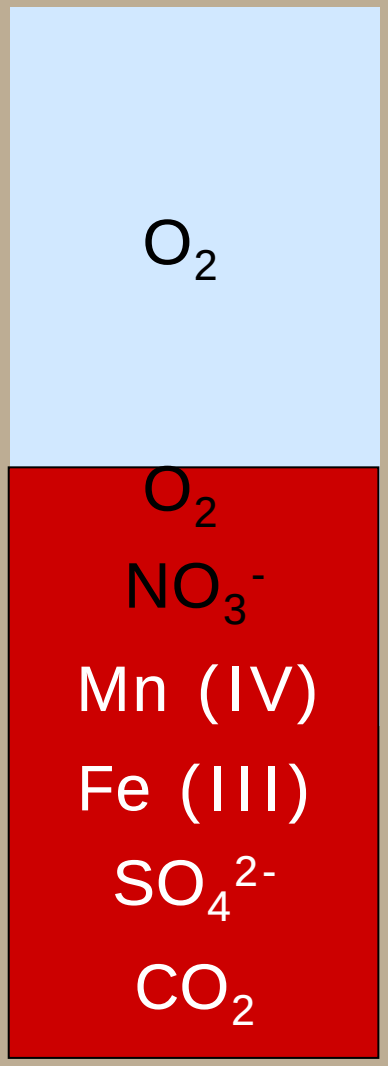
Réduit la vie des conduites de 20 ans

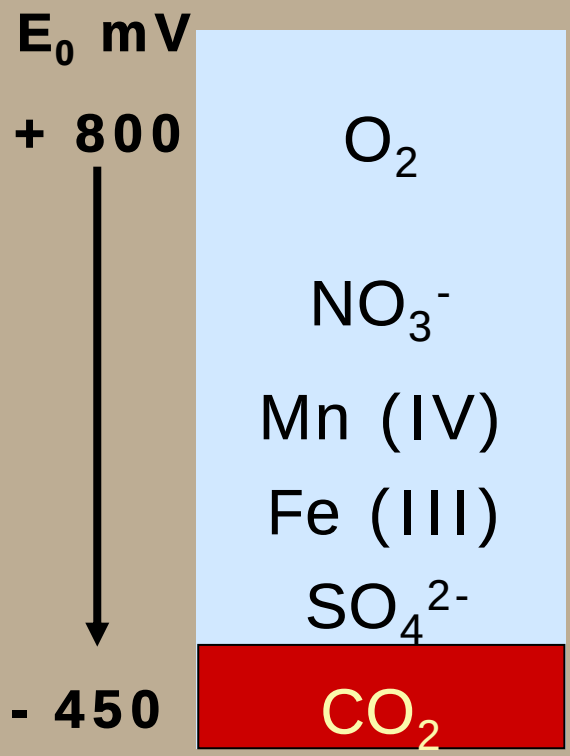
Très réactif!

H_2S <--> HS^- + H^+

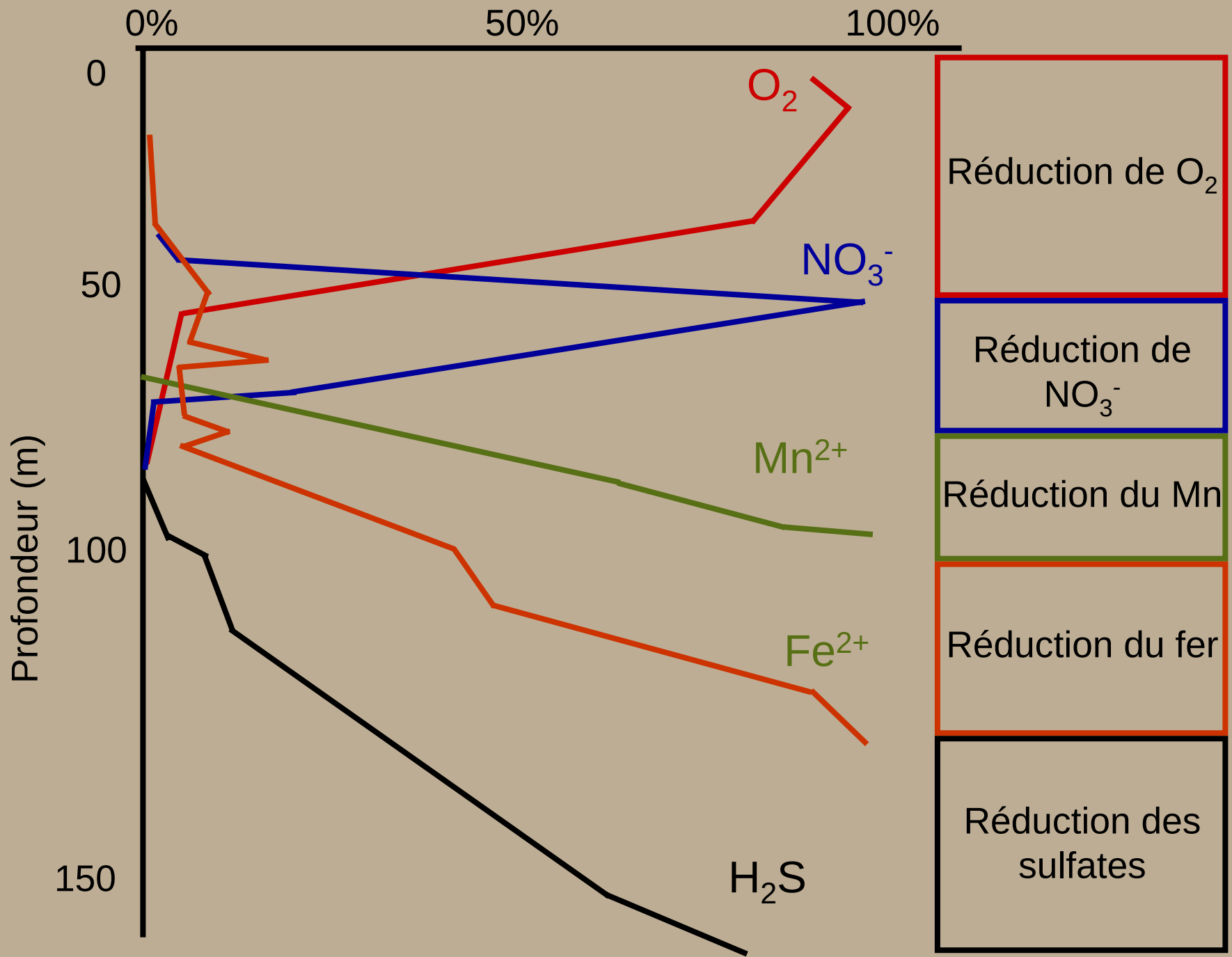
Relation entre les cycles

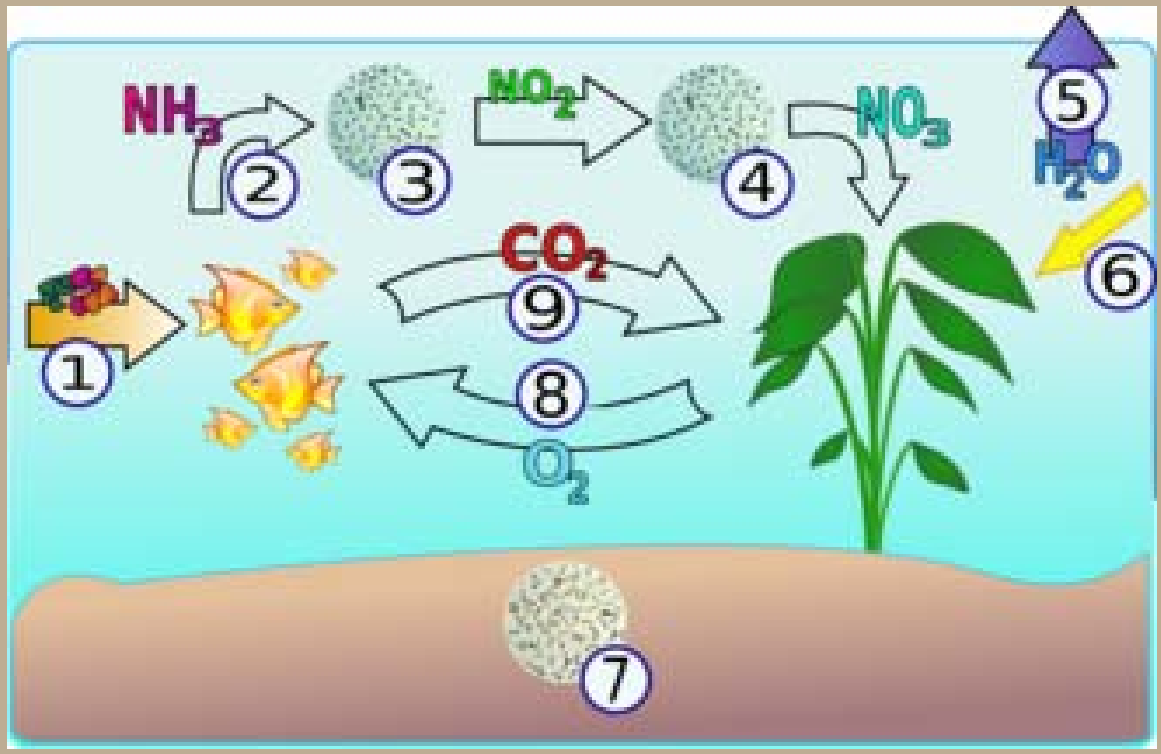
Répartition spatiale





Stratification
thermique ou saline


0%
50%
100%
0
50
100
150
Profondeur (m)
O_2
NO_3^-
Mn^{2+}
Fe^{2+}
H_2S
Réduction de O_2
Réduction de NO_3^-
Réduction du Mn
Réduction du fer
Réduction des sulfates



Syndrome du nouvel aquarium