

Methanogenesis on Earth today: Where, Who and How?

Daniel Prieur

Université de Bretagne Occidentale

Brest, France

Objectives

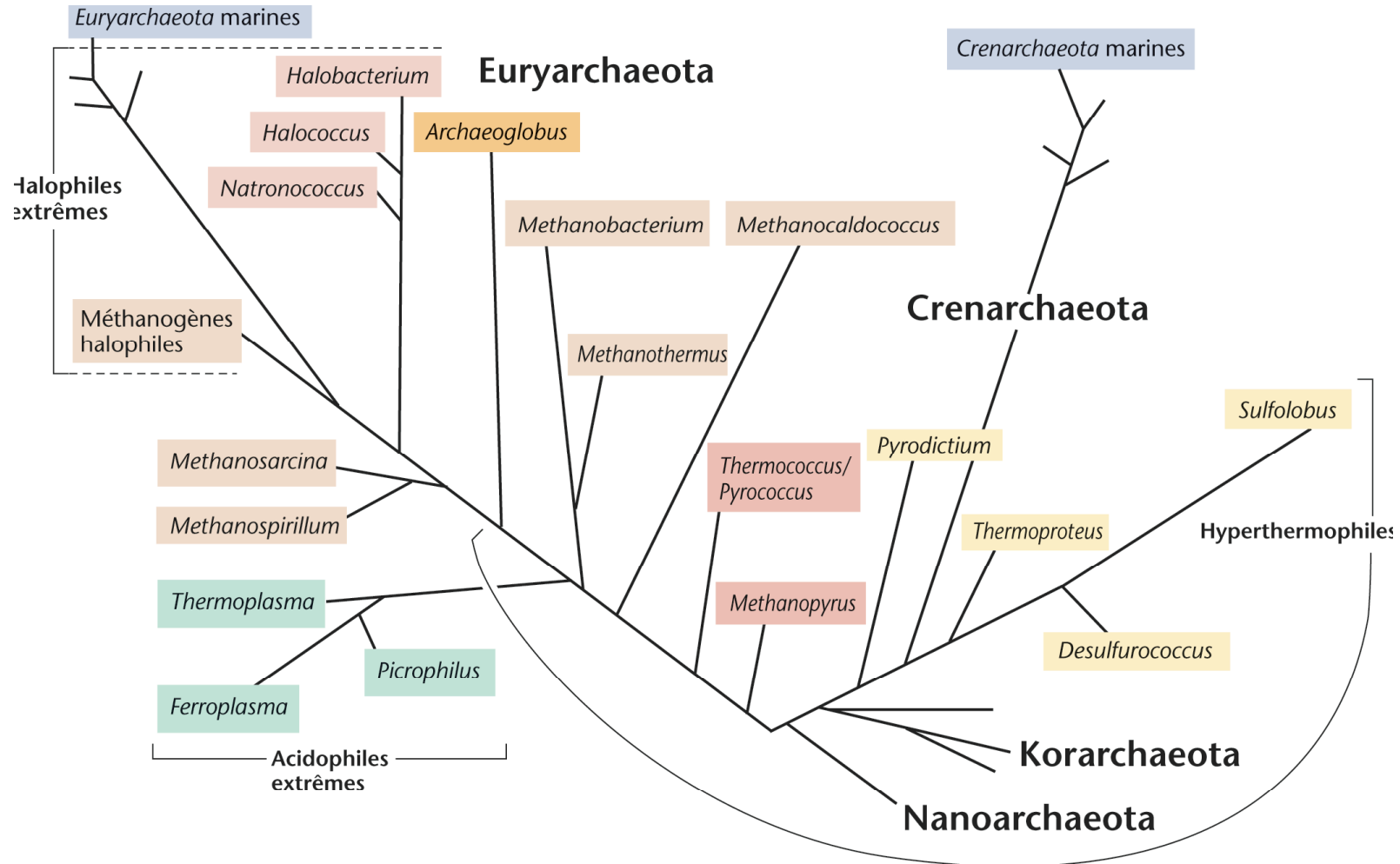
- Not a research paper
- Summary of knowledge on methanogenesis
- Earth references for interpretation of Martian data

Methane production on Earth

- 500-600 Tg methane/year
- About 74%: biogenic
- Natural sources: 21-47%
 - Wetlands: 15-40%
 - Termites: 3%
 - Oceans: 2-3%
 - Methane hydrates: 1-2%
- Anthropogenic sources: 45-80
 - Ruminants: 13-19%
 - Energy generation: 13-18%
 - Rice agriculture: 7-17%
 - Landfills: 6-12%
 - Biomass burning: 4-9%
 - Waste treatment: 2-4%

Where Biogenic methane is produced?

Who are the biological producers?



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Methanogenic Archaea only produce Methane as an end product of their energetic metabolism

Taxinomic Diversity

- Methanomicrobiales
 - Methanobacteriaceae
 - Methanothermaceae
- Methanococcales
 - Methanococcaceae
 - Methanocaldococcaceae
- Methanomicrobiales
 - Methanomicrobiaceae
 - Methanocorpusculaceae
 - Methanospirillaceae
- Methanosarcinales
 - Methanosarcinaceae
 - Methanosaetaceae
- Methanopyrales

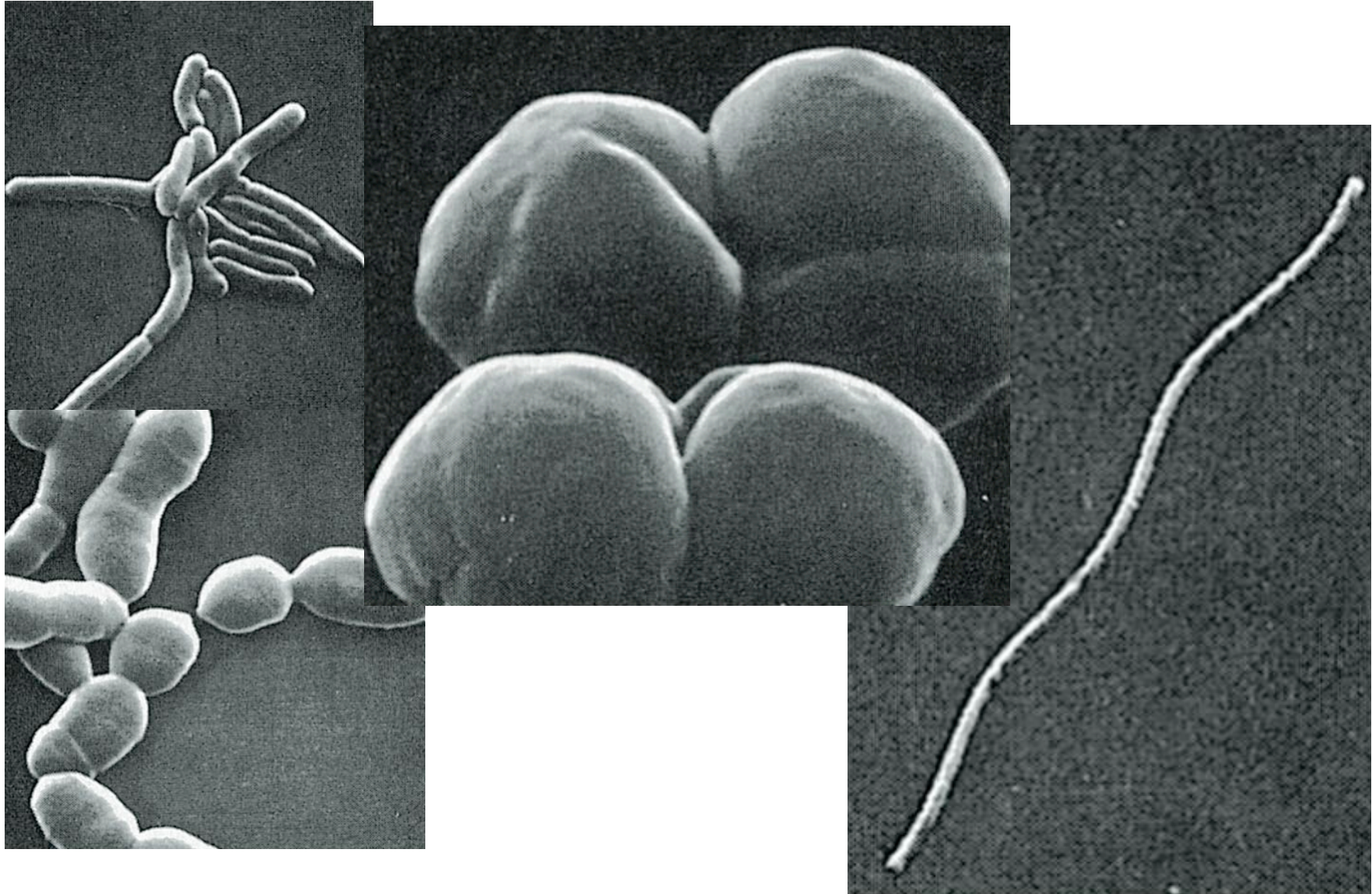
Physiology

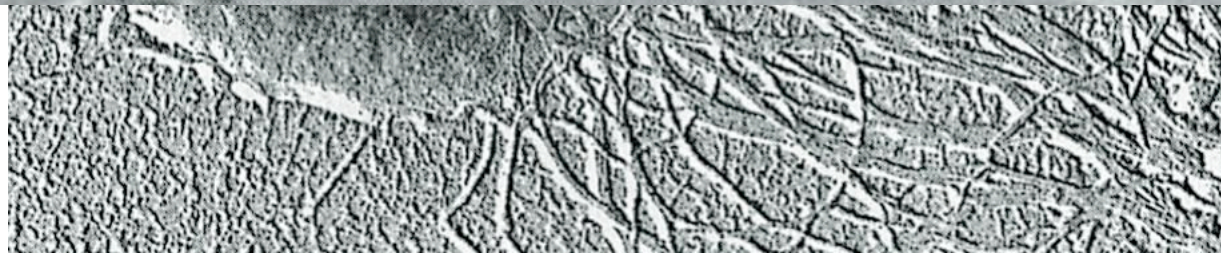
- Temperature range
 - 4 to 110°C
- pH range
 - 6 to 8, but acidophiles (5,6) and alcaliphiles (9,2)
- Salinity range
 - Variable, fresh waters, marine waters, salt ponds

Growth versus Activity

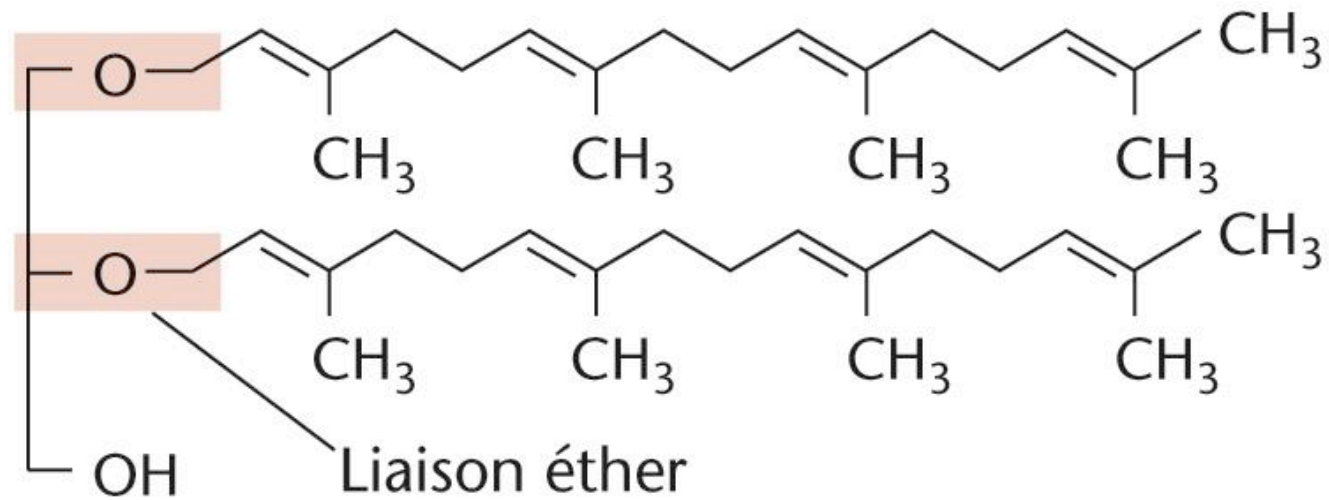
- Growth (cell division)
 - -4°C to 110°C (Methanopyrus)
- Activity (methane production)
 - -16,5°C (Galichinsky) up to 123°C (Takai)
- Dormancy

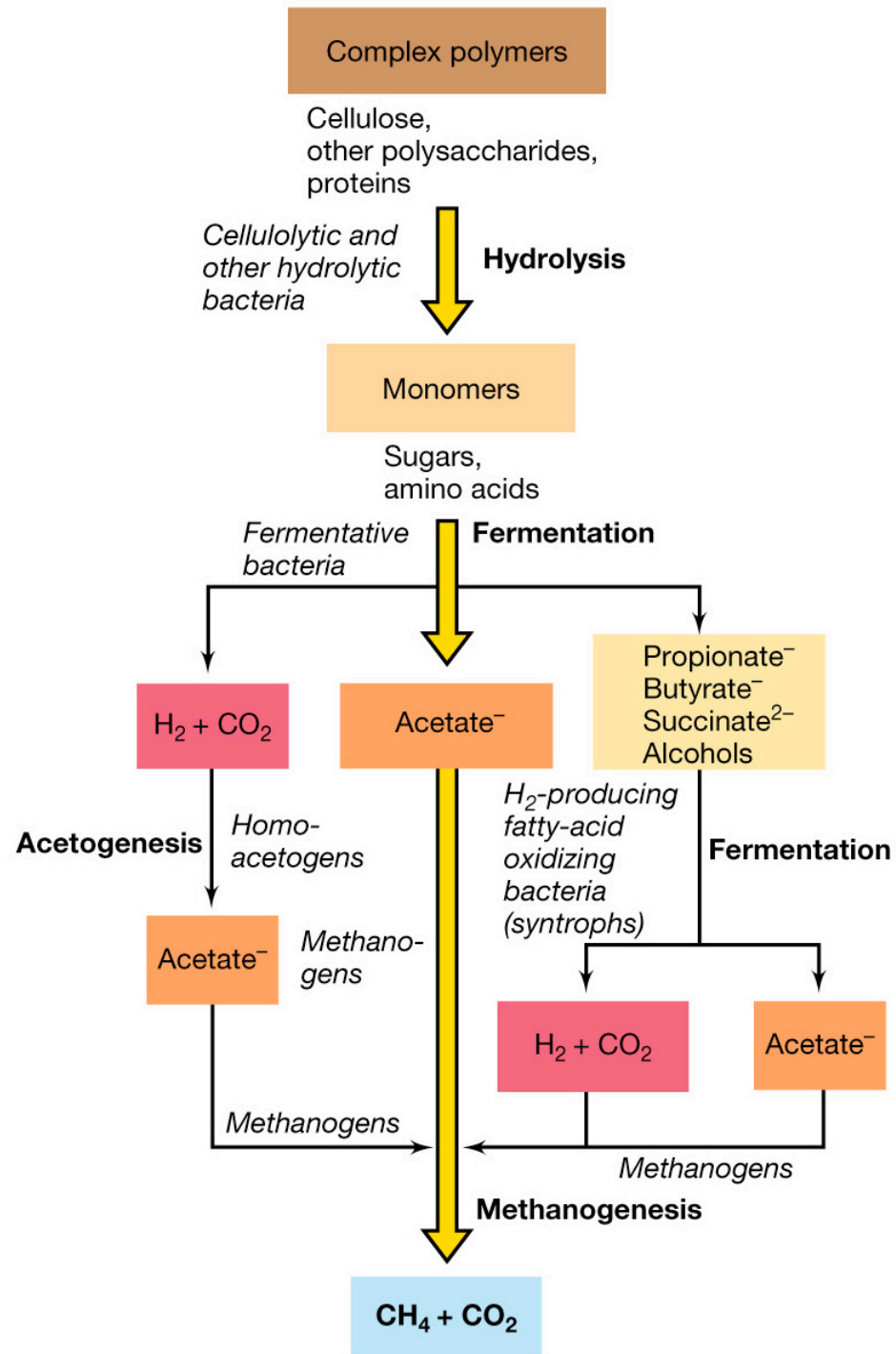
Various morphologies





Specific lipids

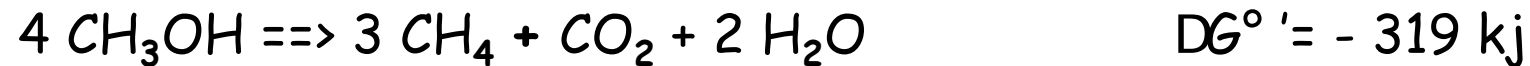




Substrates for methanogenesis

- CO_2 type
 - Carbone dioxide
 - Carbon monoxide
 - Formate
- Methyl type
 - Methanol (CH_3OH), Methylamine (CH_3NH_3^+), di and tri-methylamine ($(\text{CH}_3)_3\text{NH}^+$, Methylmercaptan (CH_3SH), Dimethylsulphur ($(\text{CH}_3)_2\text{S}$)
- Acetate type
 - Acetate (CH_3COO^-)
 - Pyruvate ($\text{CH}_3\text{COCOO}^-$)

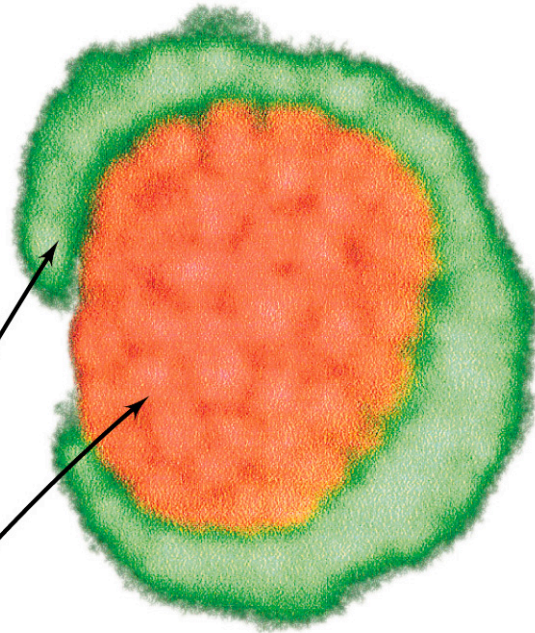
Energy production for methanogenesis



Fate of methane

- Escape to atmosphere
- Gas hydrates
- Aerobic methane oxidation
- Anaerobic methane oxidation

Anaerobic oxidation of methane

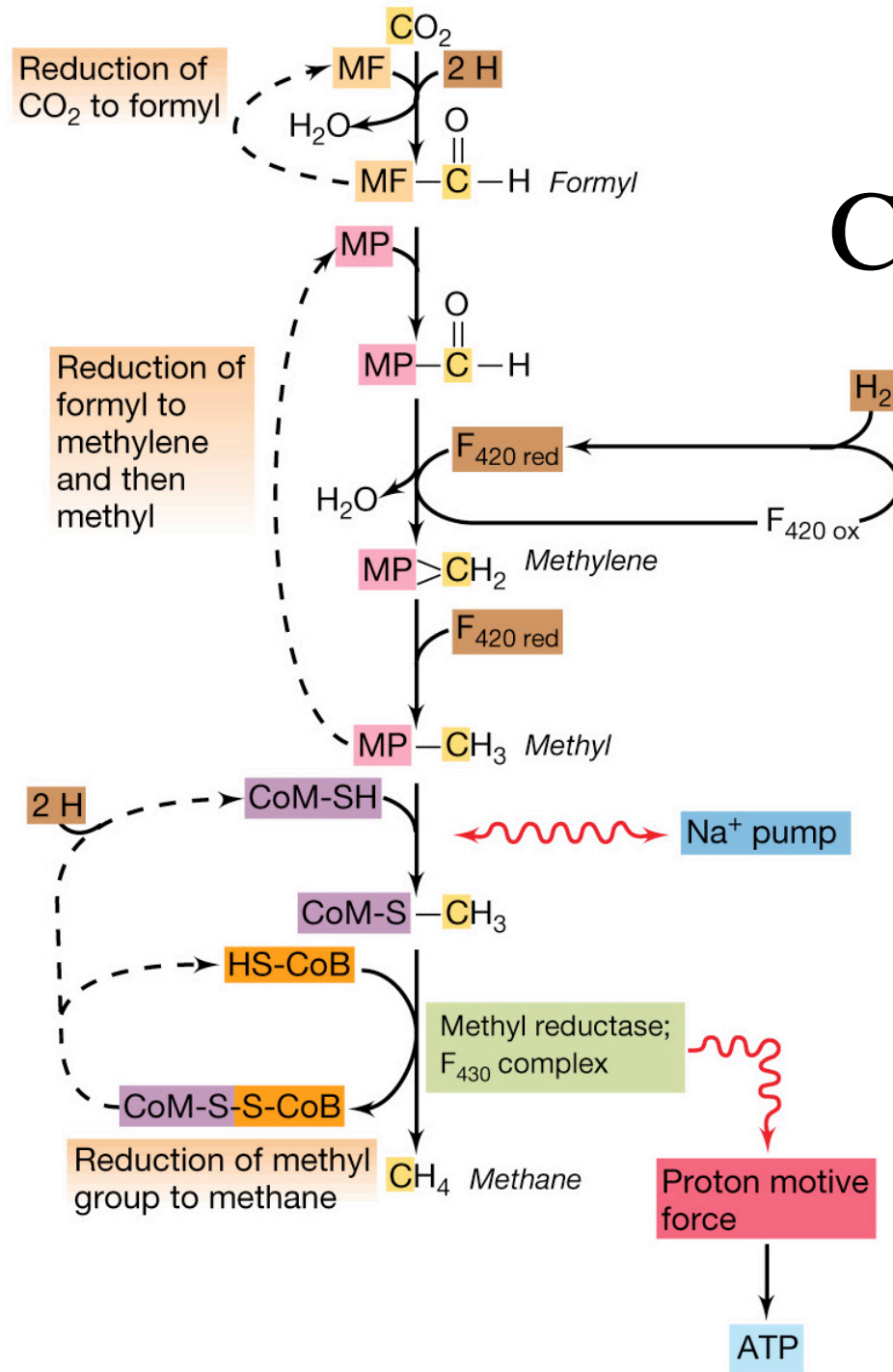


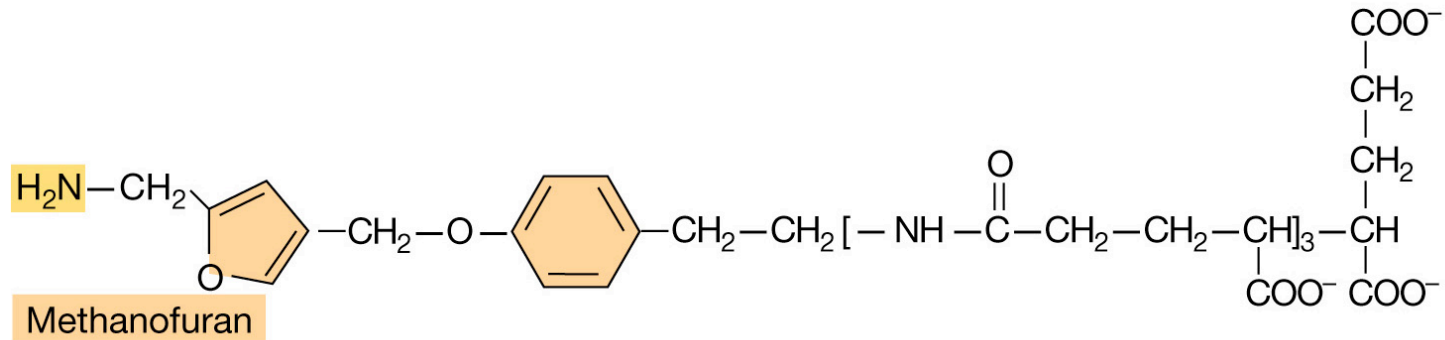
Antje Boetius and Armin Gieseke

	Reaction	Organism	$\Delta G^{0'}$ (kJ)
(a)	$\text{CH}_4 + 2 \text{H}_2\text{O} \longrightarrow \text{CO}_2 + 4 \text{H}_2$	Methanogen	+131
	$\text{SO}_4^{2-} + 4 \text{H}_2 + \text{H}^+ \longrightarrow \text{HS}^- + 4 \text{H}_2\text{O}$	Sulfate-reducer	-156
<hr/>			
	Sum: $\text{SO}_4^{2-} + \text{CH}_4 \longrightarrow \text{HCO}_3^- + \text{HS}^- + \text{H}_2\text{O}$	Syntrophic reaction	-25

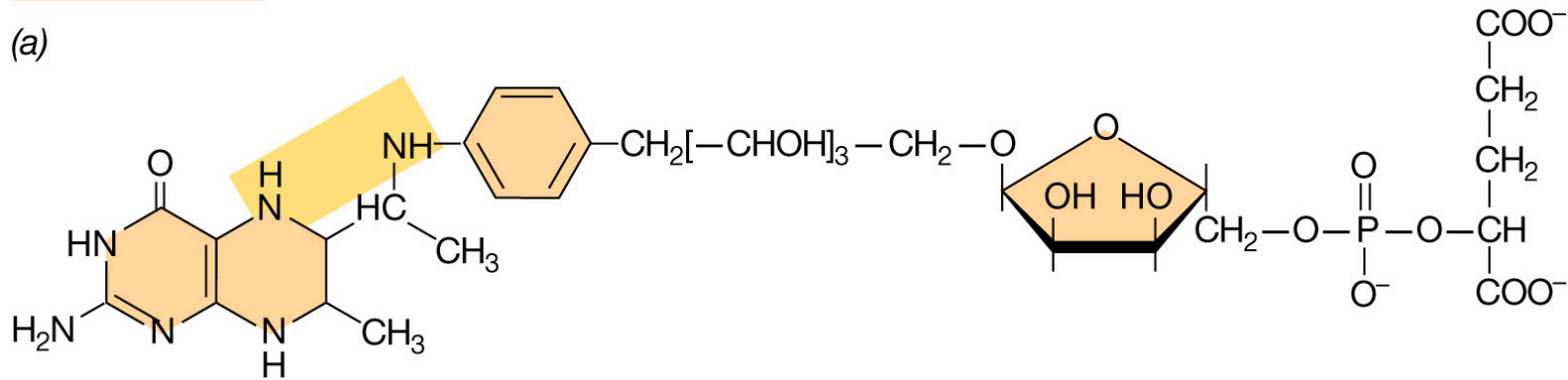
(b)

Complexity





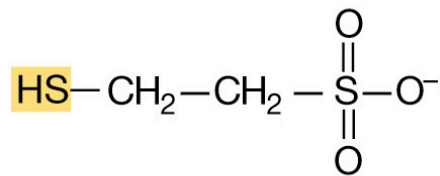
(a)



(b)

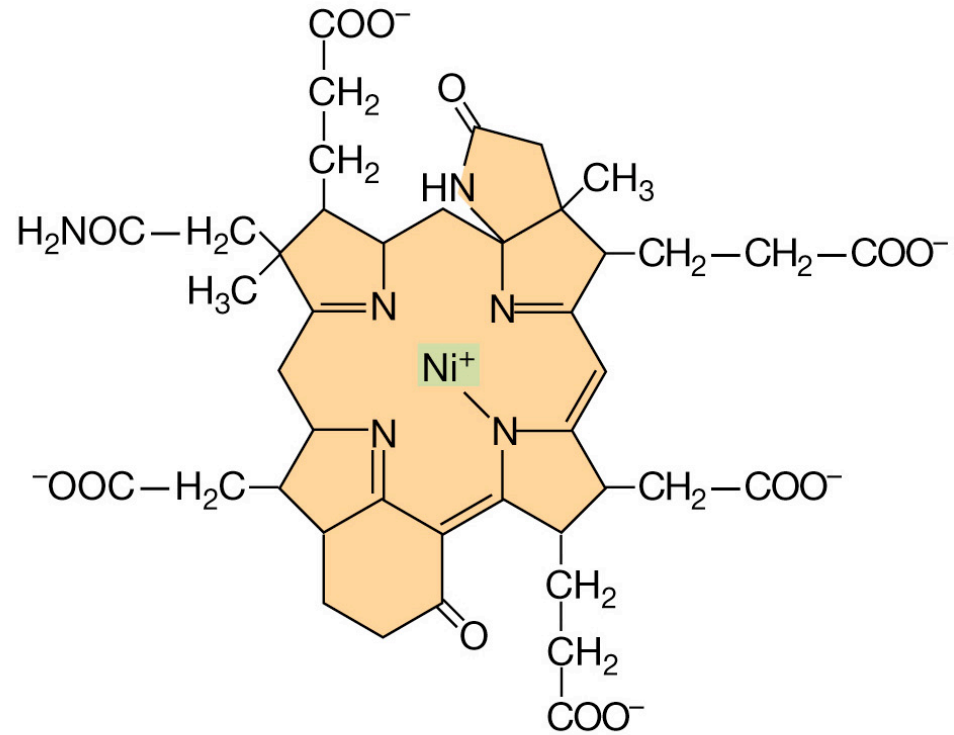
Molecules involved in methanogenesis

Molecules involved in methanogenesis



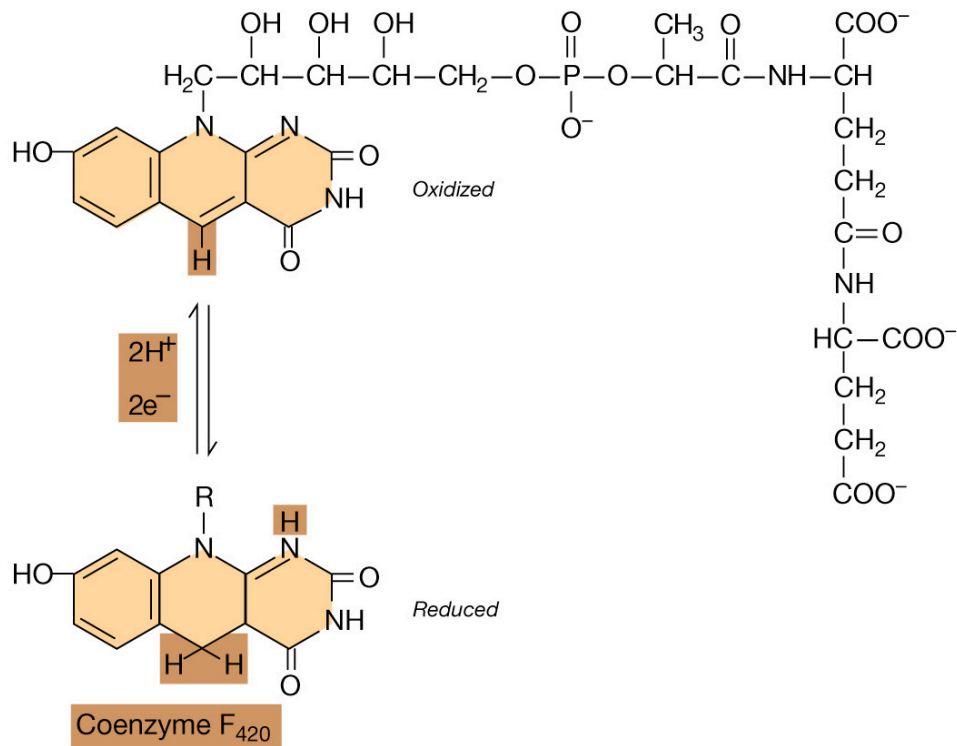
Coenzyme M (CoM)

(c)

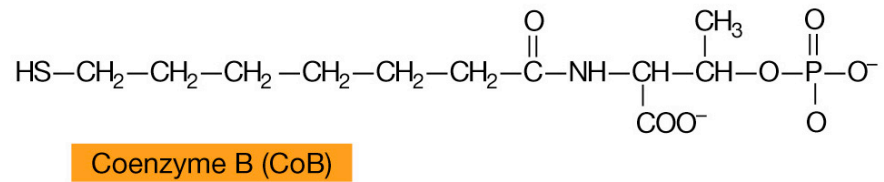


Coenzyme F₄₃₀

(d)



(e)



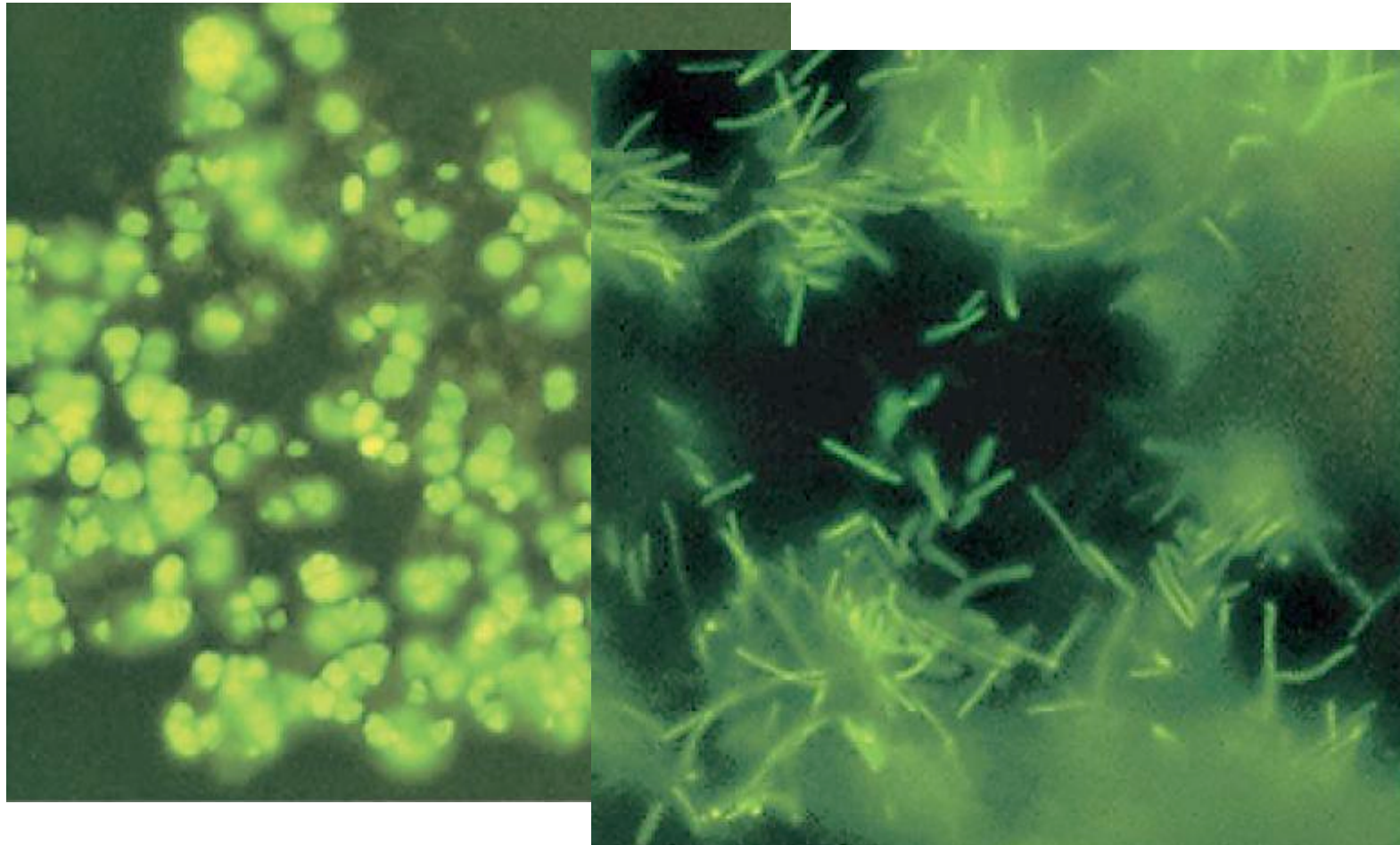
(f)

Molecules involved in methanogenesis

Methane production by non-methanogens?

- *Archaeoglobus fulgidus* (Euryarchaeota)
 - Sulphate reducer

Natural fluorescence of factor F



How many and how much?

- Hydrate ridge
 - 100-1000 cells/g sediment
 - 0,06 fmol CH₄/cell/day
- Lake sediments
 - 31,5 fmol CH₄/cell/day
- Deep marine sediments
 - 15 pmol CH₄/cm₃/day
- Anaerobic reactors
 - 108-135 fmol CH₄/cell/day