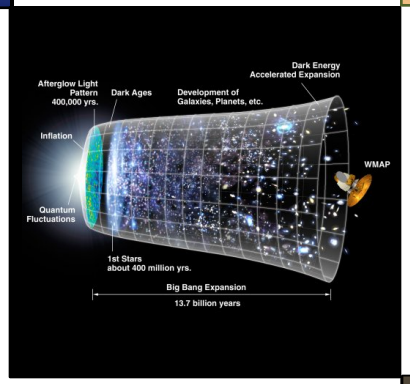
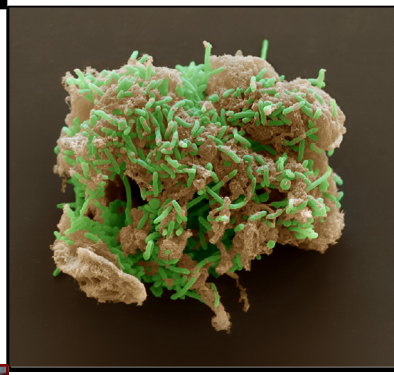


Det tidligste Liv

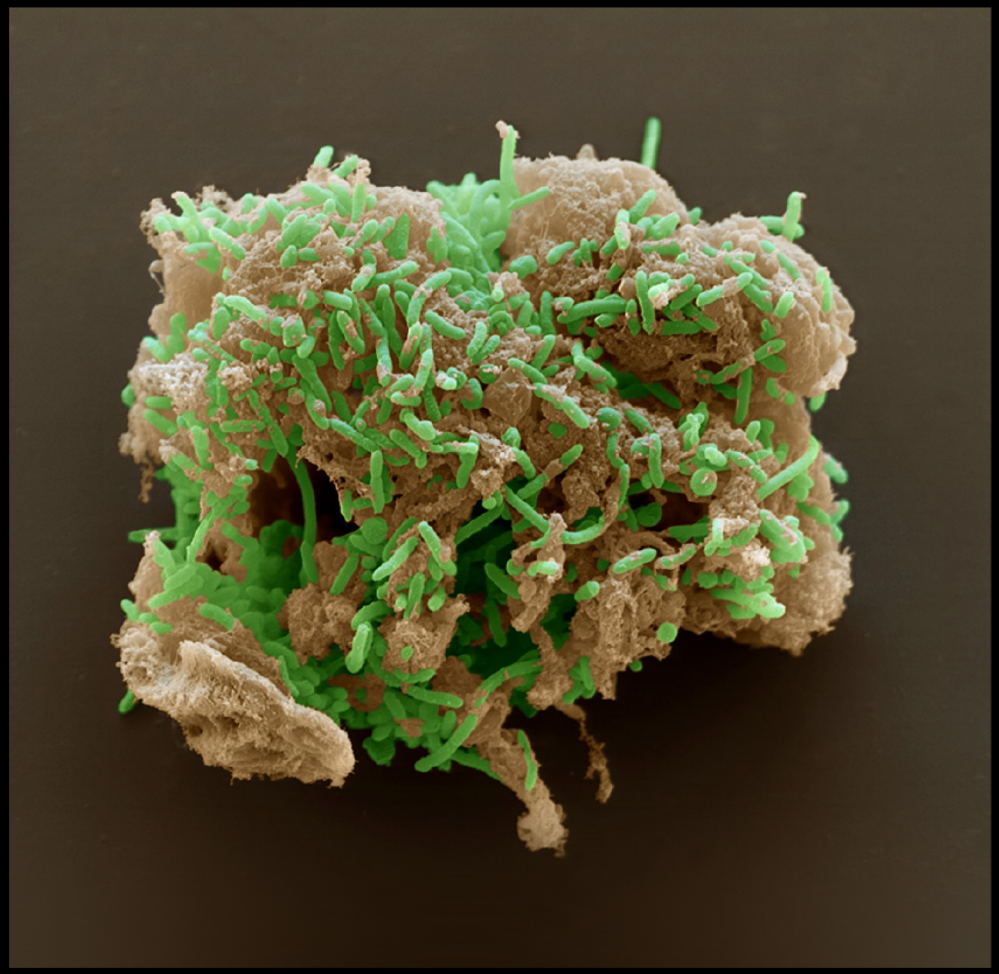
Tais W. Dahl

Lektor, Geobiologi, GLOBE Institute, Københavns Universitet
Adjungeret professor, China University of Geosciences, Wuhan



Carlsberg
CARLSBERG FOUNDATION

DANMARKS FRIE FORSKNINGSFOND



En verden af ~~liv~~ mikrober

Båndet jernmalm

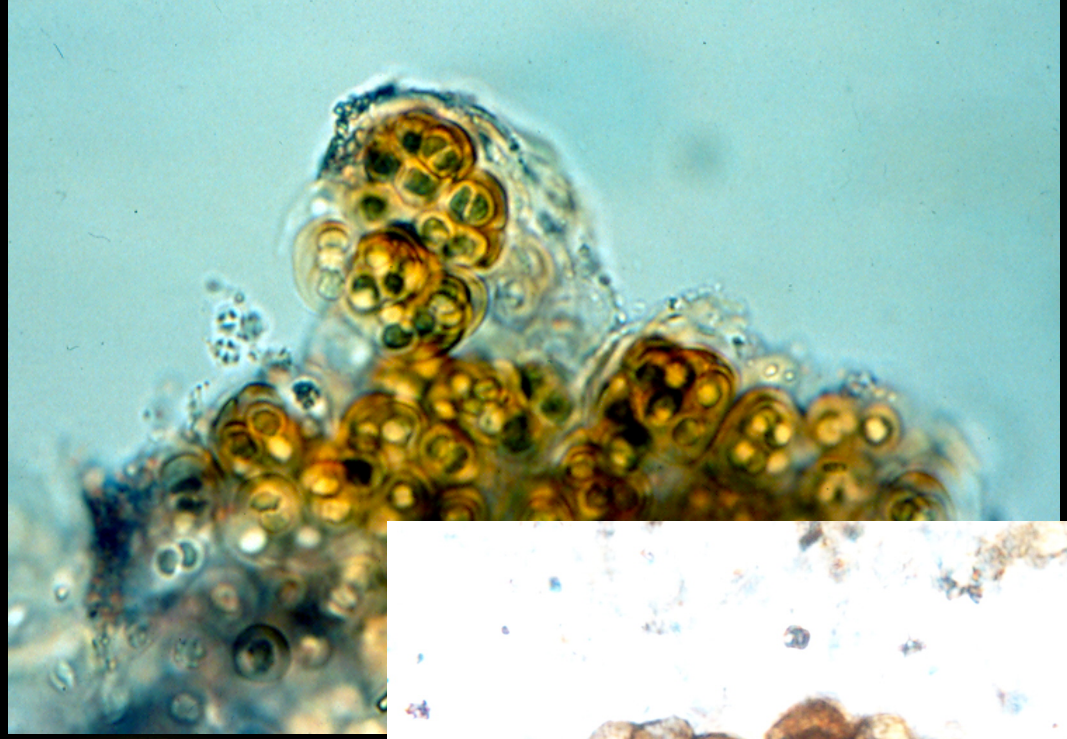
2.7 Ga
Båndet jernmalm
Ontario, Canada

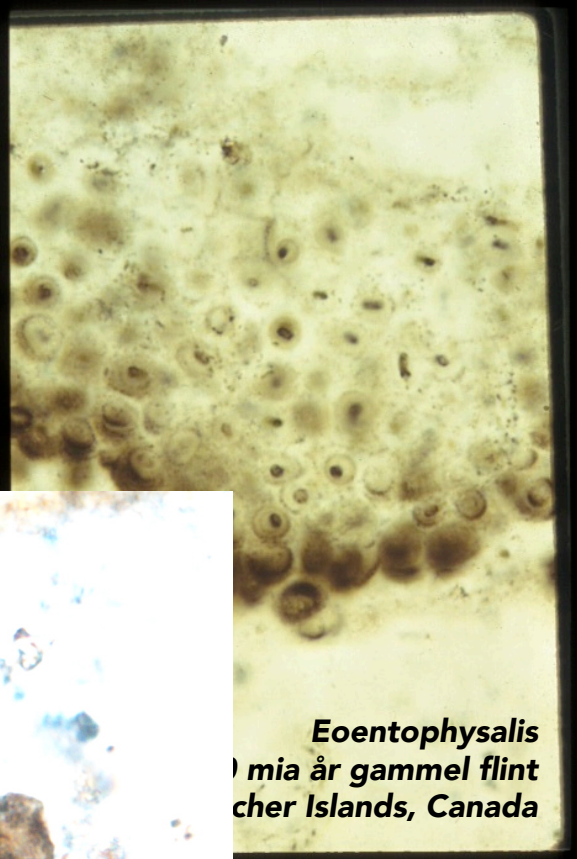
Hamersley Iron Formation

Ca. 600 millioner år gammel havbund

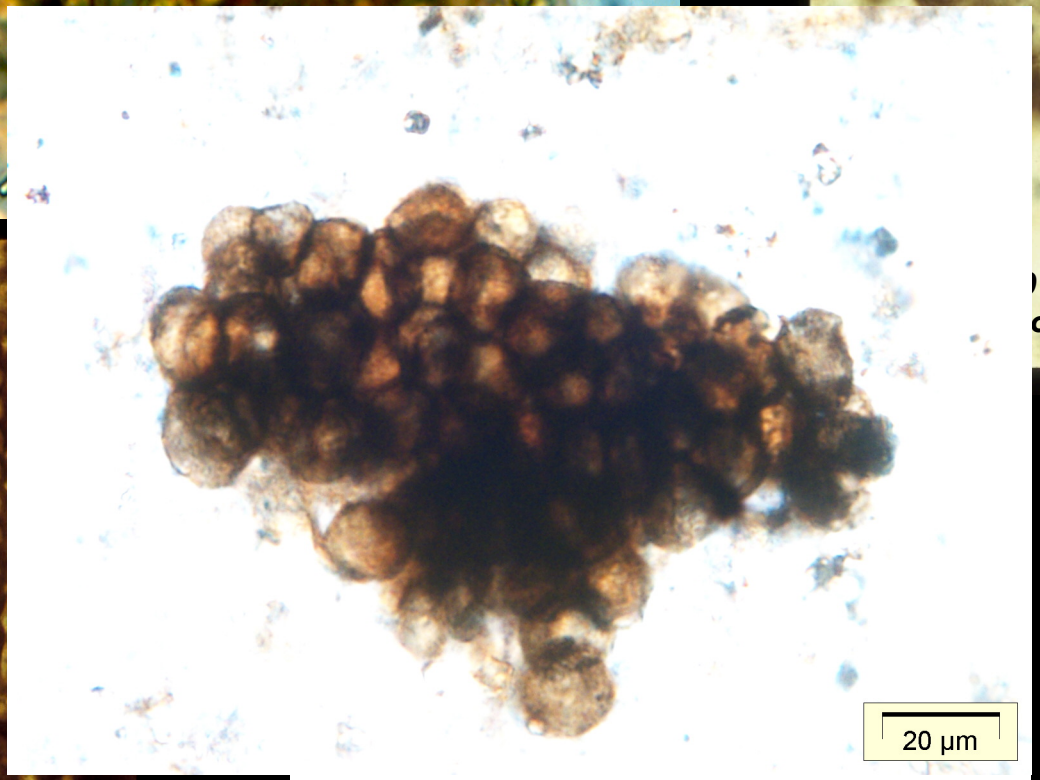
Huqf Supergroup, Oman, 2009


STABILO
OHPen universal
F

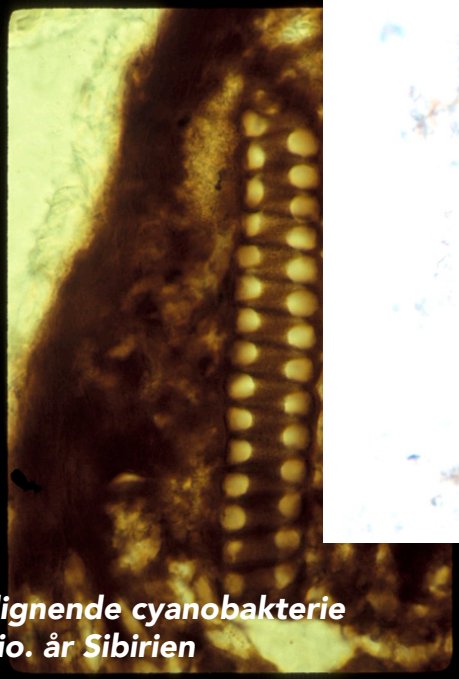




Eoentophysalis
) mia år gammel flint
cher Islands, Canada



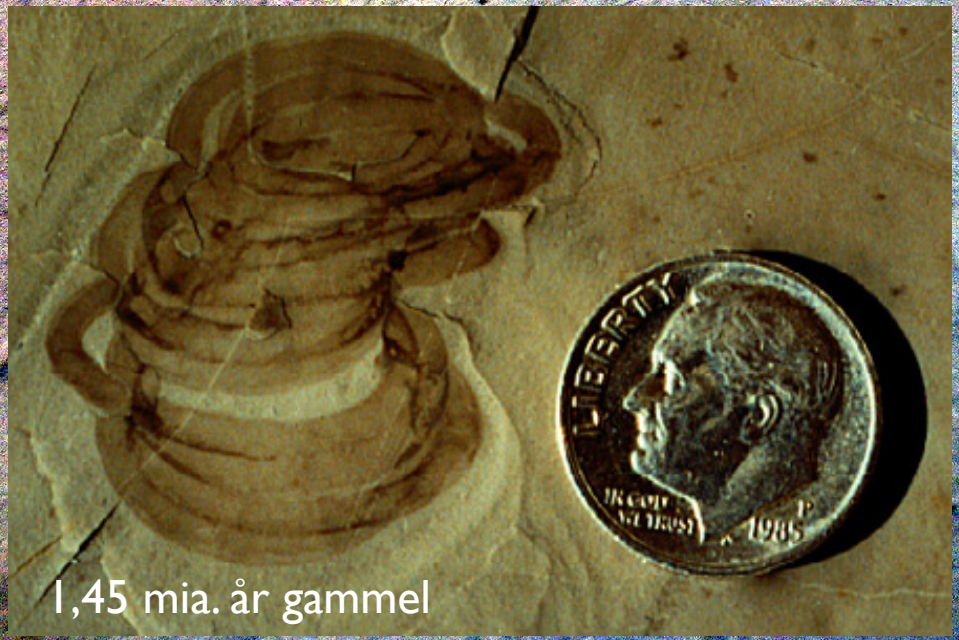
Myxococcoides cantabrigiens
Draken Formationen, Svalbard
~800 mio. år gammel



Spirogyra-lignende cyanobakterie
635-542 mio. år Sibirien

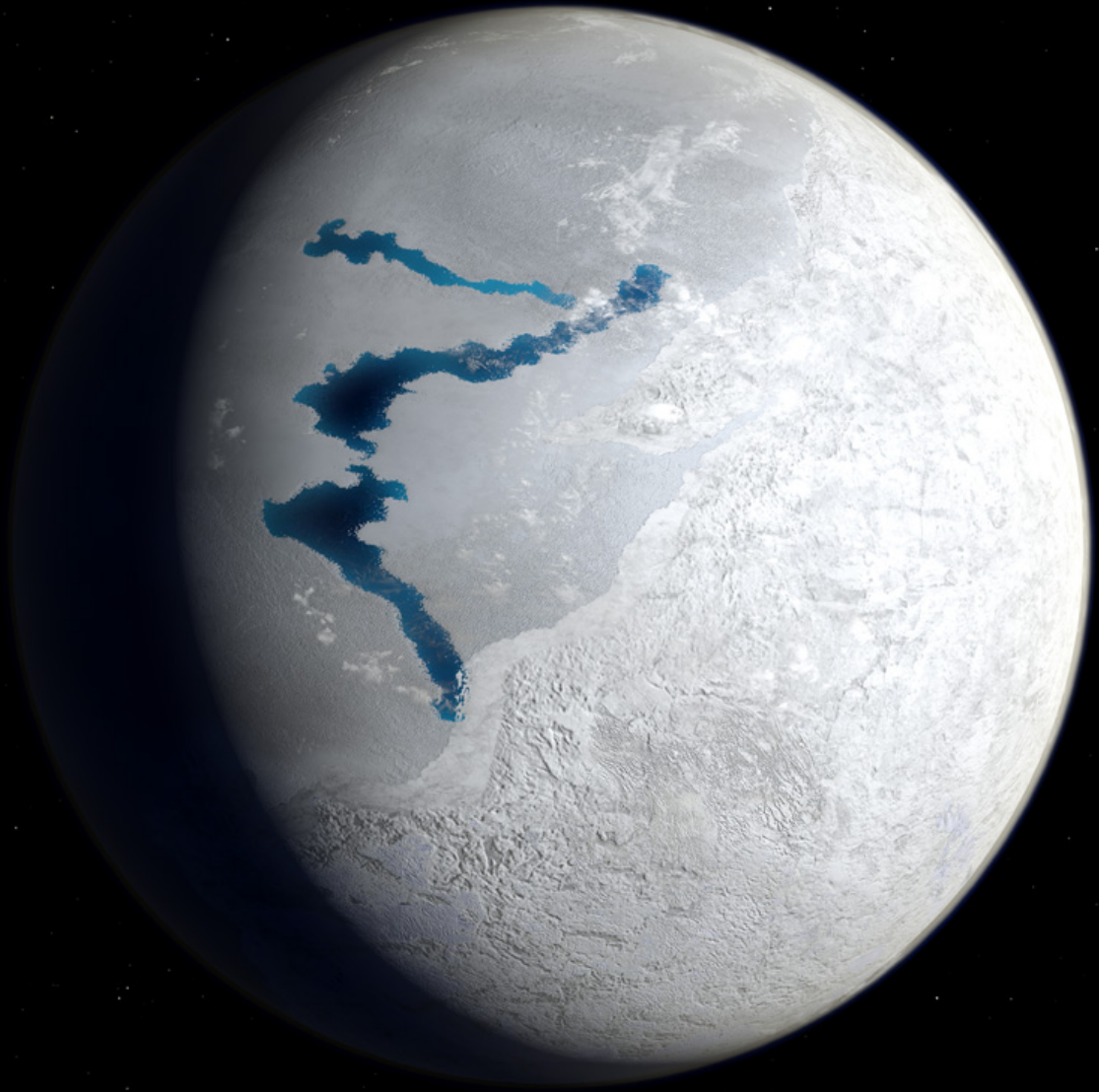
Grypania

det ældste eukaryote fossil?

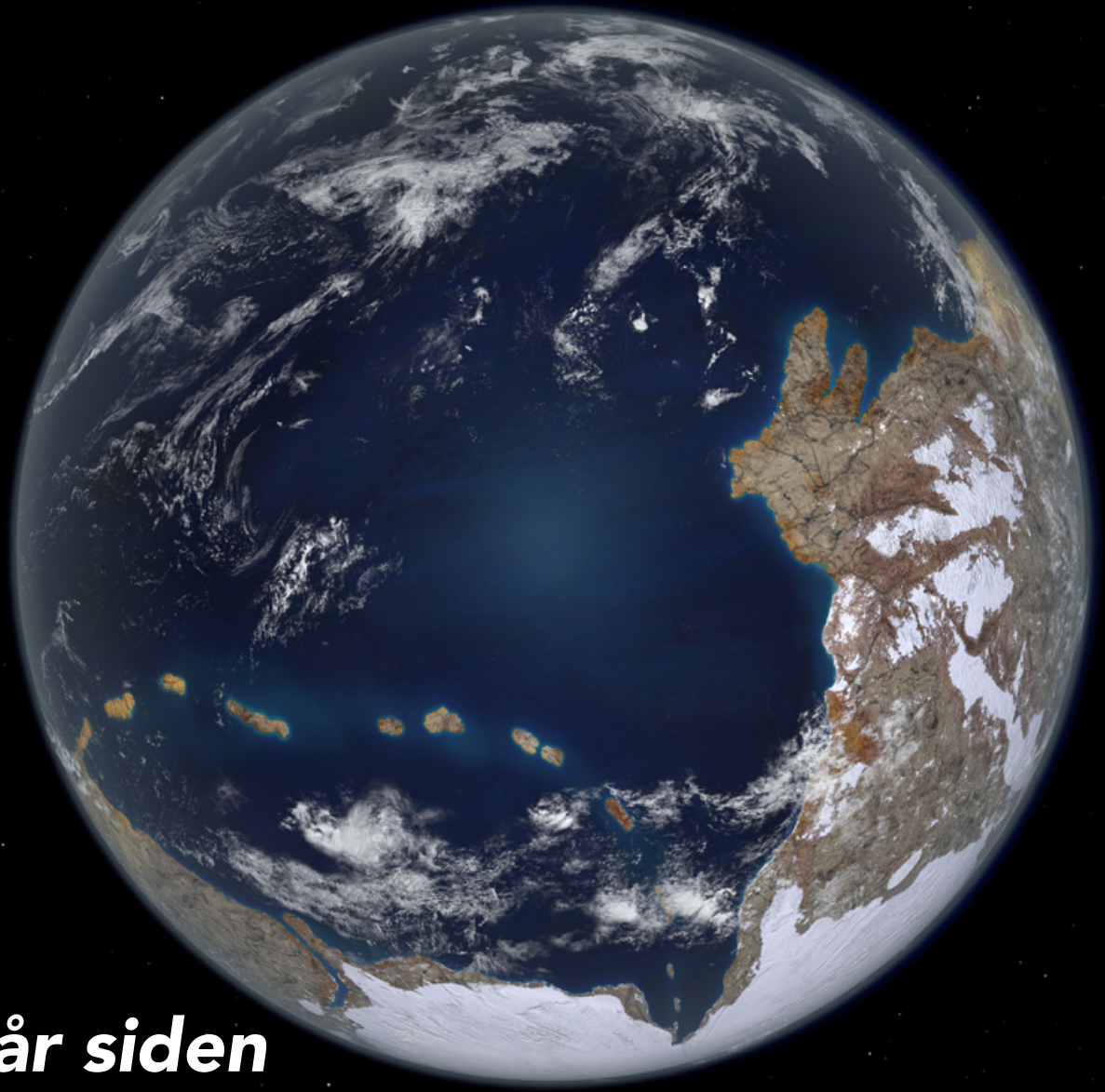


1,45 mia. år gammel

1,87 mia år gammel

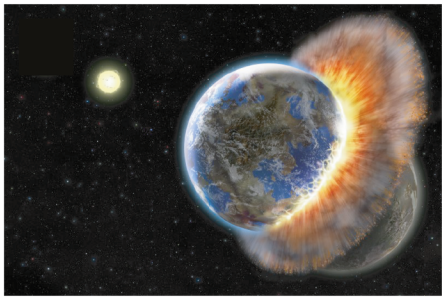


Jorden
635 mio. år siden

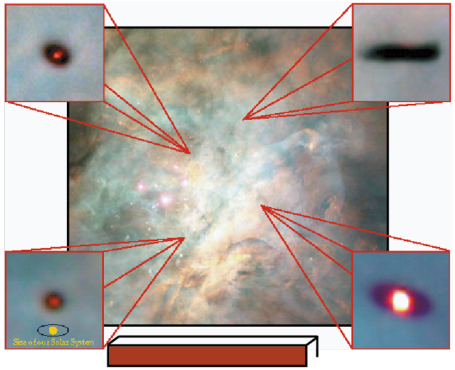


Jorden
600 mio. år siden

Hvornår opstod det første liv?



Earth-Moon forming Impact, 4.5 Ga

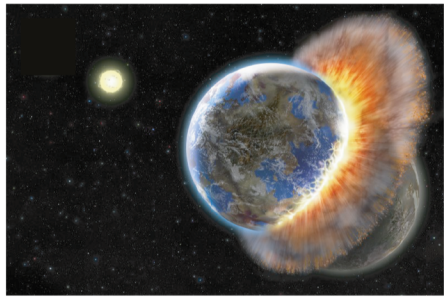


First condensates
in the Solar System
4.57 Ga

Hadean
Archean
Proterozoic
Phanerozoic

4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

Age (Ga)



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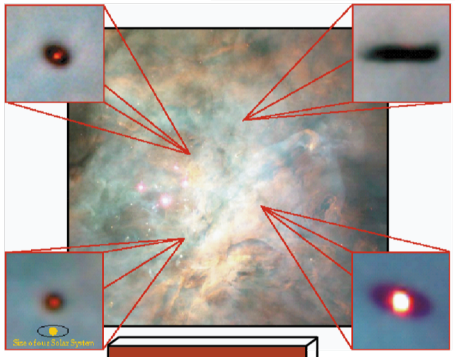


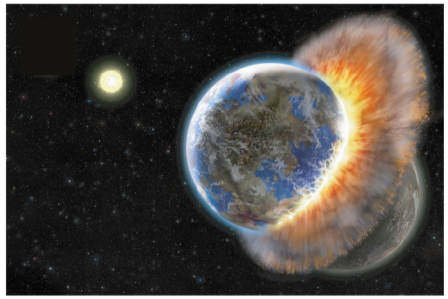
First condensates
in the Solar System
4.57 Ga

Origin of mountains and continents
ca. 4.0-3.5 Ga

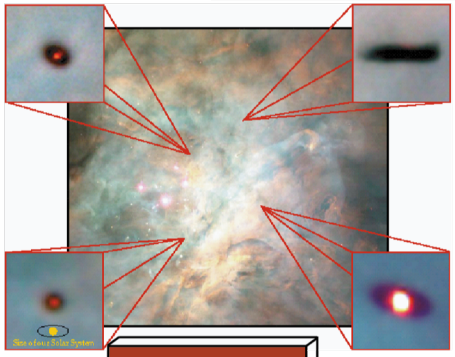
Hadean
Archean
Proterozoic
Phanerozoic

4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

Age (Ga)



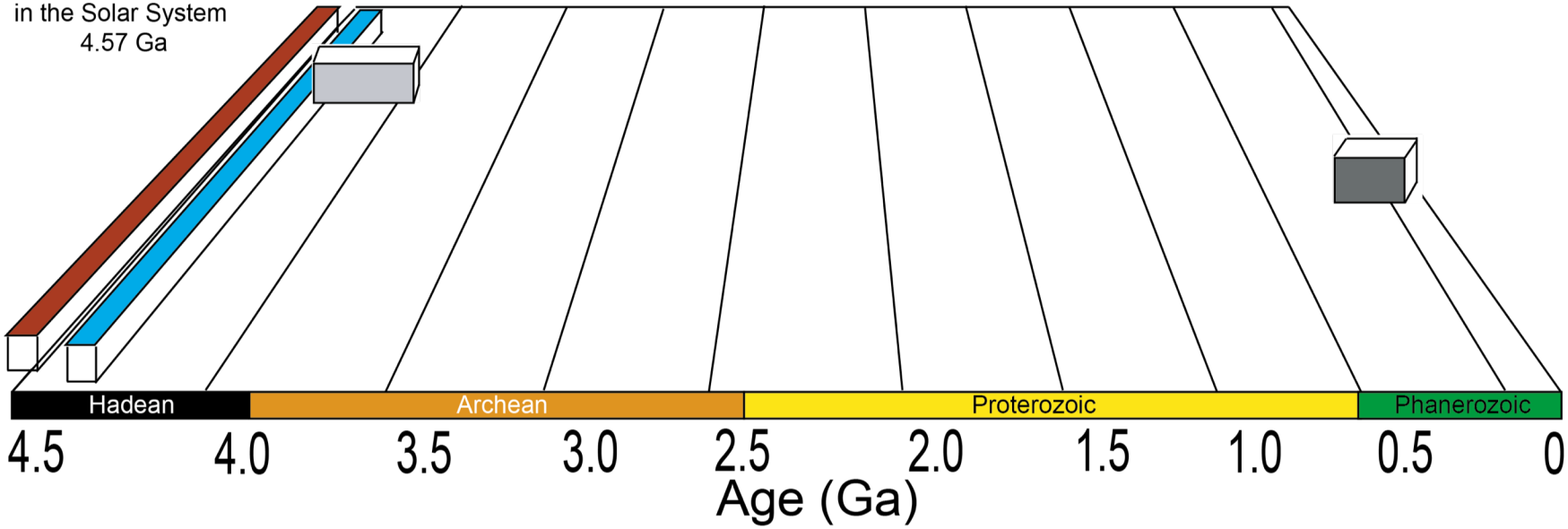
Earth-Moon forming Impact, 4.5 Ga

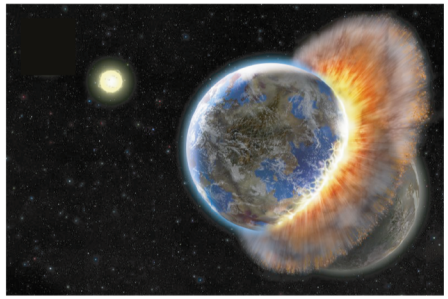


First condensates
in the Solar System
4.57 Ga

Origin of mountains and continents
ca. 4.0-3.5 Ga

Dinosaurs, 0.25-0.06 Ga





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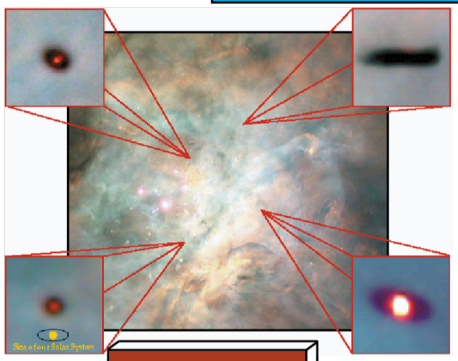


First condensates
in the Solar System
4.57 Ga

Origin of mountains and continents
ca. 4.0-3.5 Ga

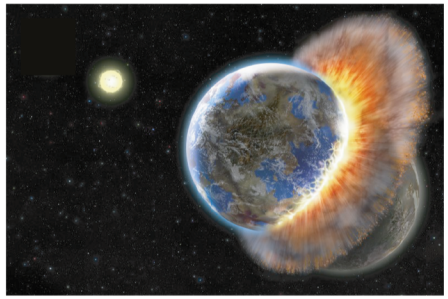
Dinosaurs, 0.25-0.06 Ga

Microbial life forms

Hadean | Archean | Proterozoic | Phanerozoic

4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

Age (Ga)



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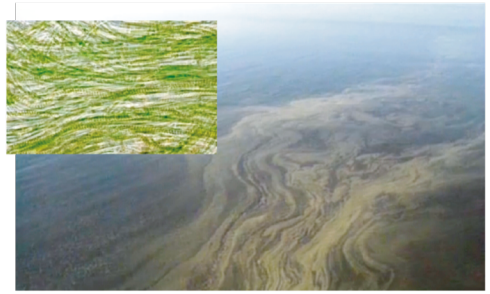
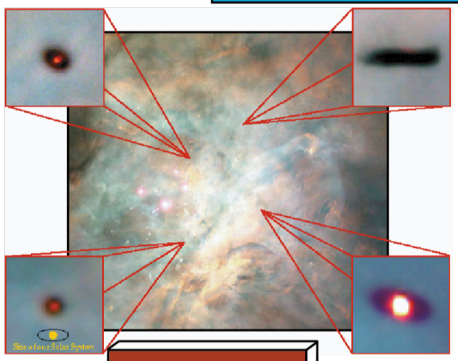


Oxygenic photosynthesis, since 3.8-2.5 Ga



First condensates
in the Solar System
4.57 Ga

Origin of mountains and continents
ca. 4.0-3.5 Ga

Dinosaurs, 0.25-0.06 Ga

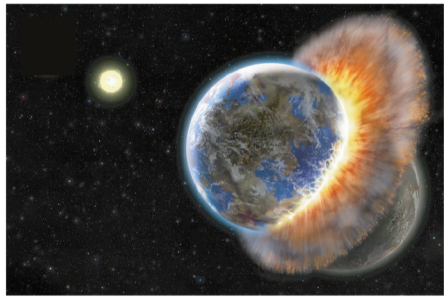
Oxygenic photosynthesis

Microbial life forms

Hadean | Archean | Proterozoic | Phanerozoic

4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

Age (Ga)



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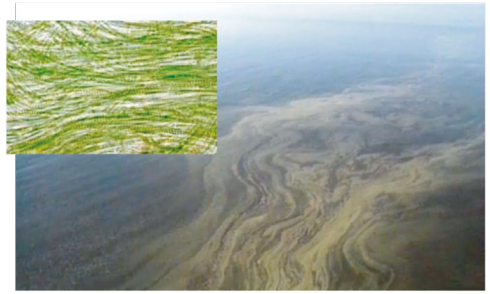

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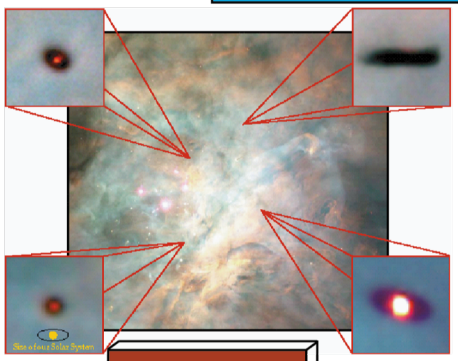


First condensates
in the Solar System
4.57 Ga

Origin of mountains and continents
ca. 4.0-3.5 Ga

Dinosaurs, 0.25-0.06 Ga

Eucaryotic cells

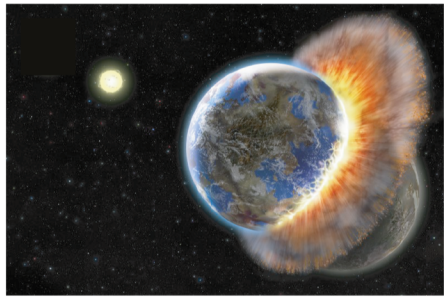
Oxygenic photosynthesis

Microbial life forms

Hadean | Archean | Proterozoic | Phanerozoic

4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

Age (Ga)



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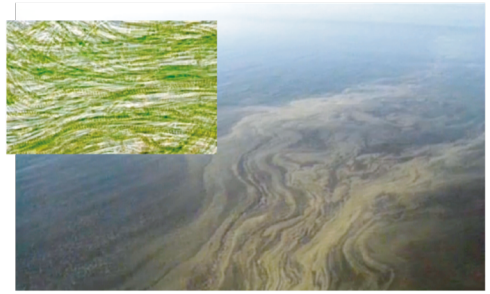

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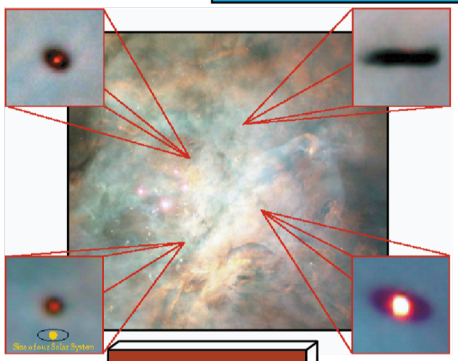


First condensates
in the Solar System
4.57 Ga

Origin of mountains and continents
ca. 4.0-3.5 Ga

Bilaterian animals, 0.54 Ga

Dinosaurs, 0.25-0.06 Ga

Animals

Eucaryotic cells

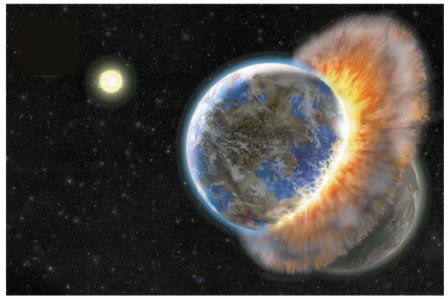
Oxygenic photosynthesis

Microbial life forms

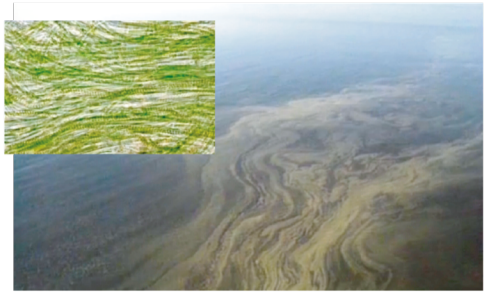
Hadean | Archean | Proterozoic | Phanerozoic

4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

Age (Ga)

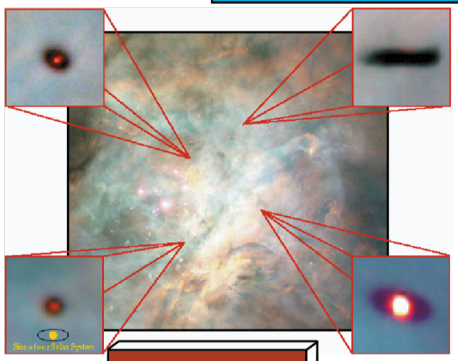


Earth-Moon forming Impact, 4.5 Ga



Oxygenic photosynthesis, since 3.8-2.5 Ga

Vascular plants, 0.42 Ga



First condensates
in the Solar System
4.57 Ga

Origin of mountains and continents
ca. 4.0-3.5 Ga

Bilaterian animals, 0.54 Ga

Dinosaurs, 0.25-0.06 Ga

Animals

Plants

Eucaryotic cells

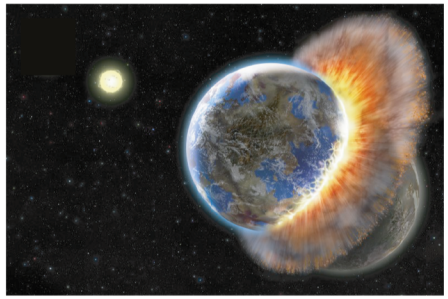
Oxygenic photosynthesis

Microbial life forms

Hadean | Archean | Proterozoic | Phanerozoic

4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

Age (Ga)



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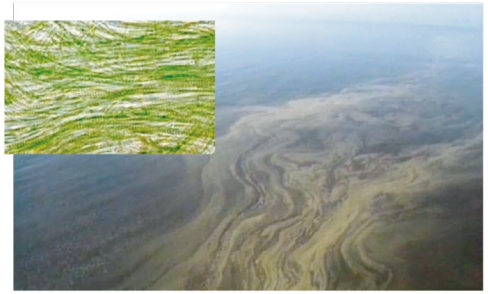
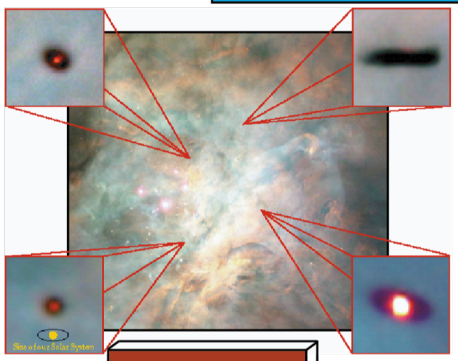


Oxygenic photosynthesis, since 3.8-2.5 Ga

Vascular plants, 0.42 Ga



First condensates
in the Solar System
4.57 Ga

Origin of mountains and continents
ca. 4.0-3.5 Ga

Bilaterian animals, 0.54 Ga

Dinosaurs, 0.25-0.06 Ga

Widespread/Snowball
glaciations

Animals

Plants

Eucaryotic cells

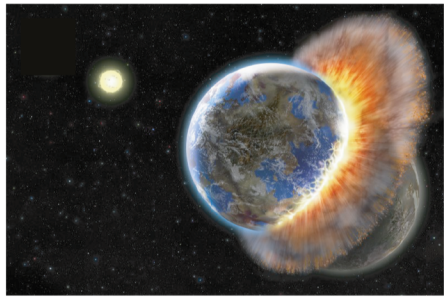
Oxygenic photosynthesis

Microbial life forms

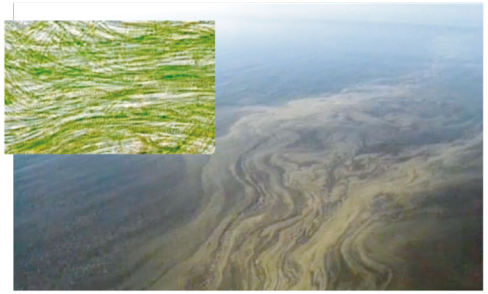
Hadean | Archean | Proterozoic | Phanerozoic

4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

Age (Ga)

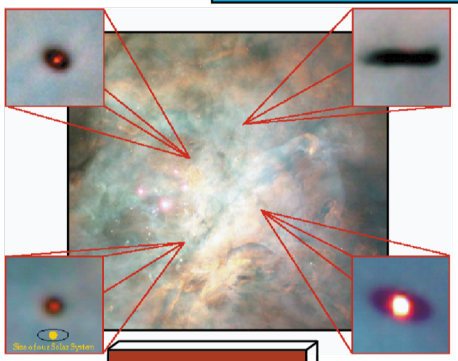


Earth-Moon forming Impact, 4.5 Ga



Oxygenic photosynthesis, since 3.8-2.5 Ga

Vascular plants, 0.42 Ga



First condensates in the Solar System 4.57 Ga

Origin of mountains and continents ca. 4.0-3.5 Ga

Bilaterian animals, 0.54 Ga

Dinosaurs, 0.25-0.06 Ga

Plausible atmospheric O_2 evolution

Animals

Plants

Eucaryotic cells

Oxygenic photosynthesis

Microbial life forms

Widespread/Snowball glaciations

Hadean | Archean | Proterozoic | Phanerozoic

4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

Age (Ga)

Betingelser for Liv

- Flydende vand (H_2O, T = 0-100°C)
- Energikilde (Sollys eller kemisk energi)
- Kulstofkilde (organiske forbindelser, CO_2)

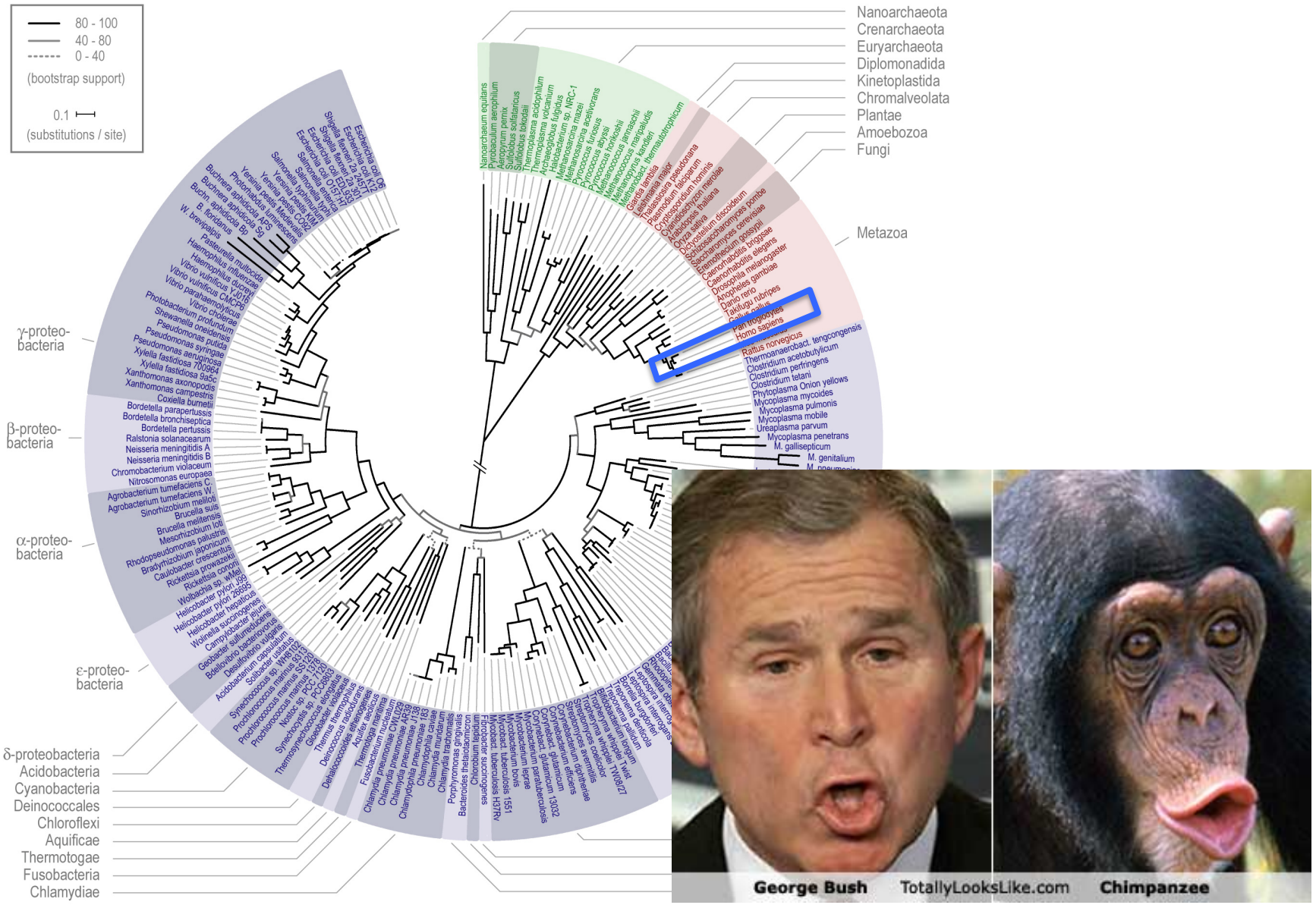
Båndet jernmalm

Hvad er liv?

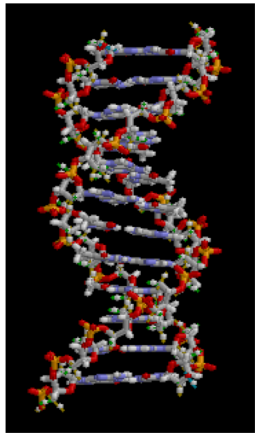
Liv = stofskifte + hukommelse

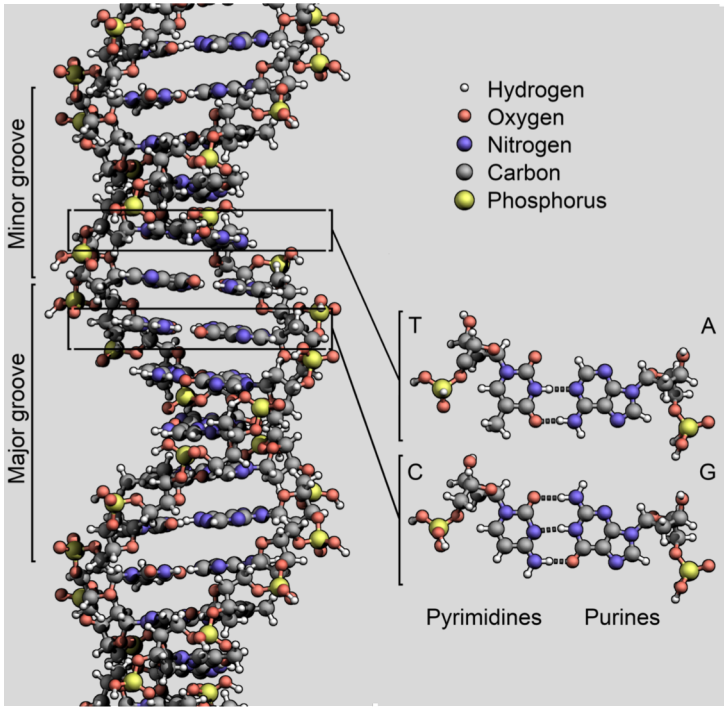
(omsætning af energi) (opskrift til den næste generation)

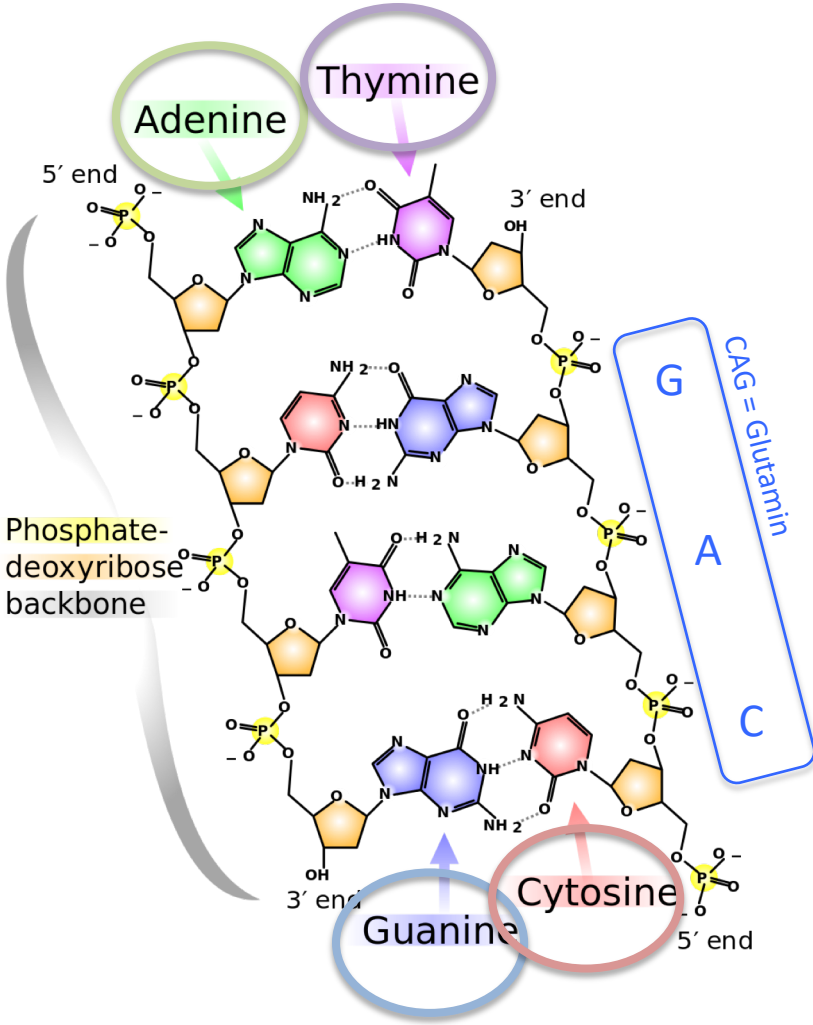
Hukommelse (den genetiske kode)



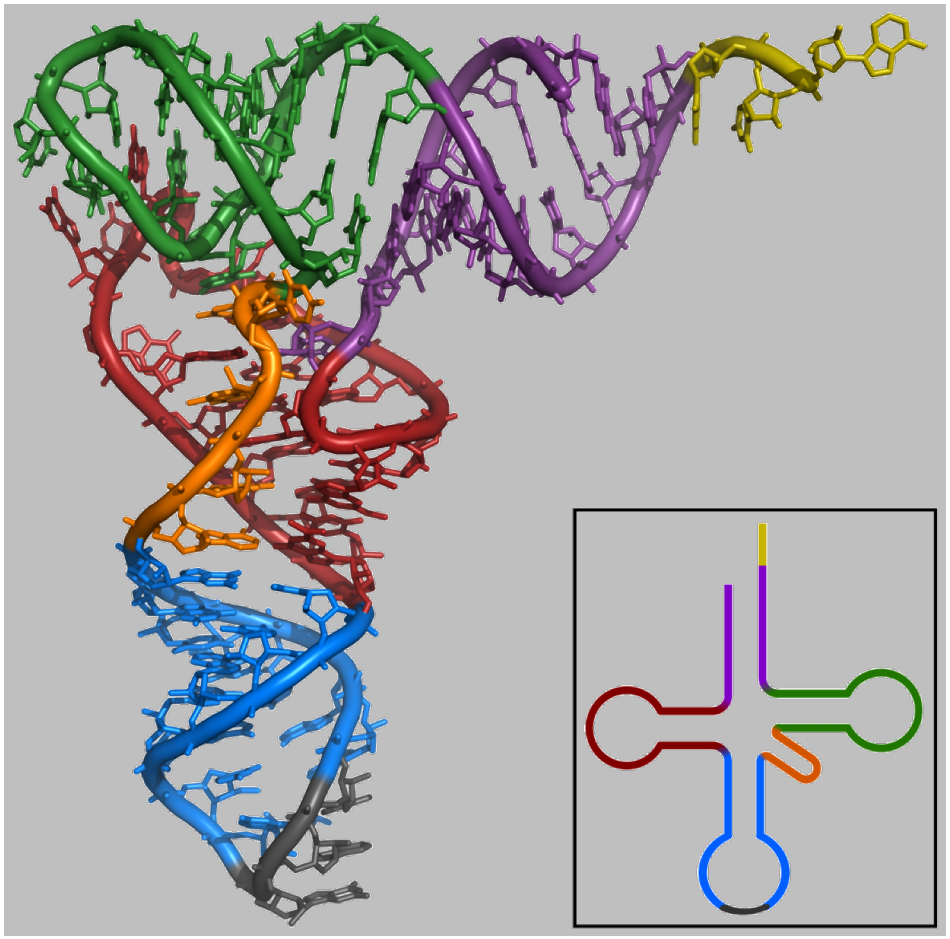
Fælles kode: DNA

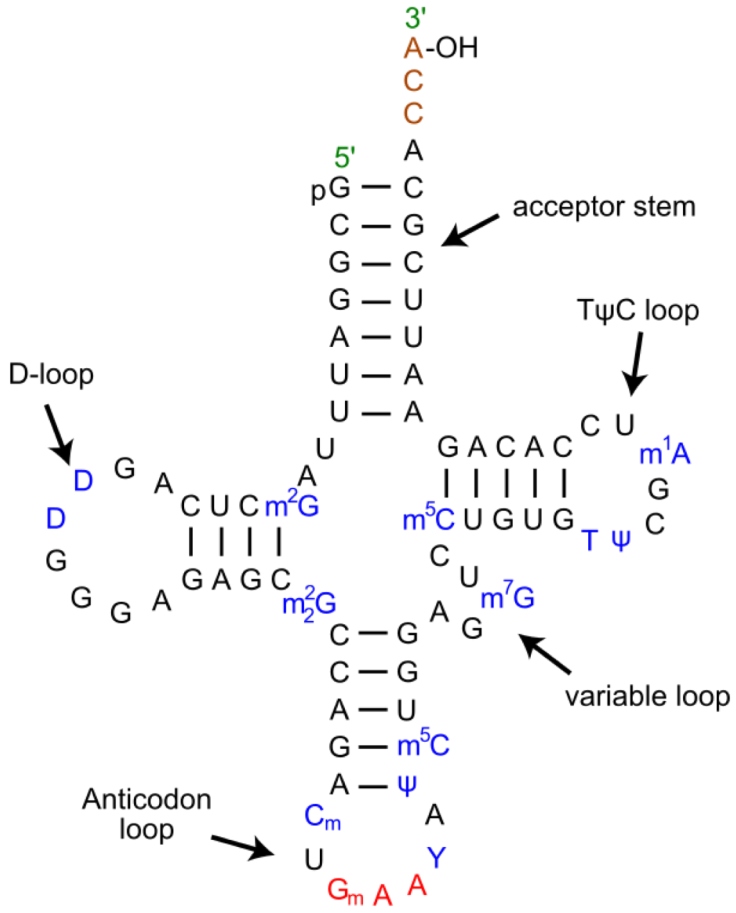






RNA (Ribonucleic Acid)





RNA kan både bære og omsætte genetisk information

(DNA) (enzym)

Stofskifte – Hvad er det?

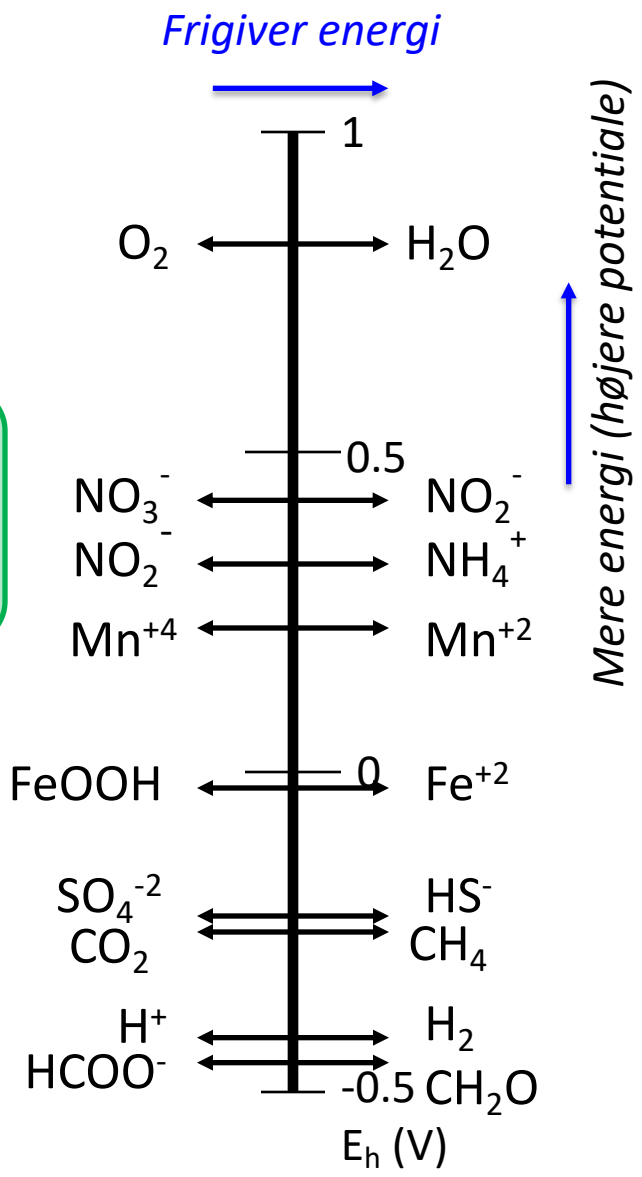
To eksempler:

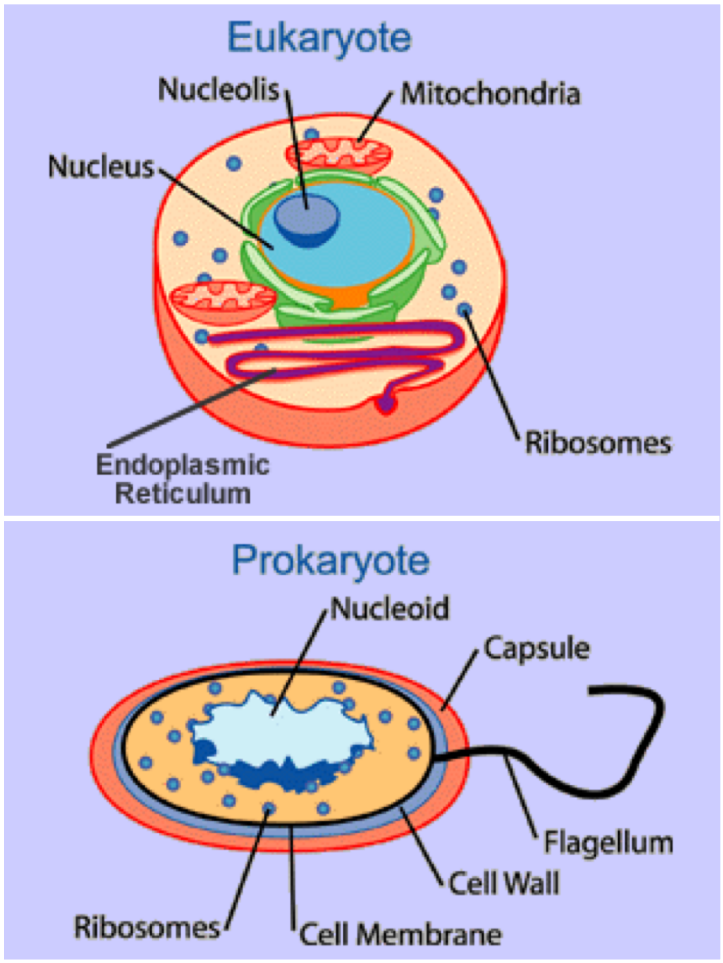
Aerob fotosyntese (med ilt)

$CO_2 + H_2O + lys \Rightarrow CH_2O + O_2$

Aerob forbrænding (med ilt)

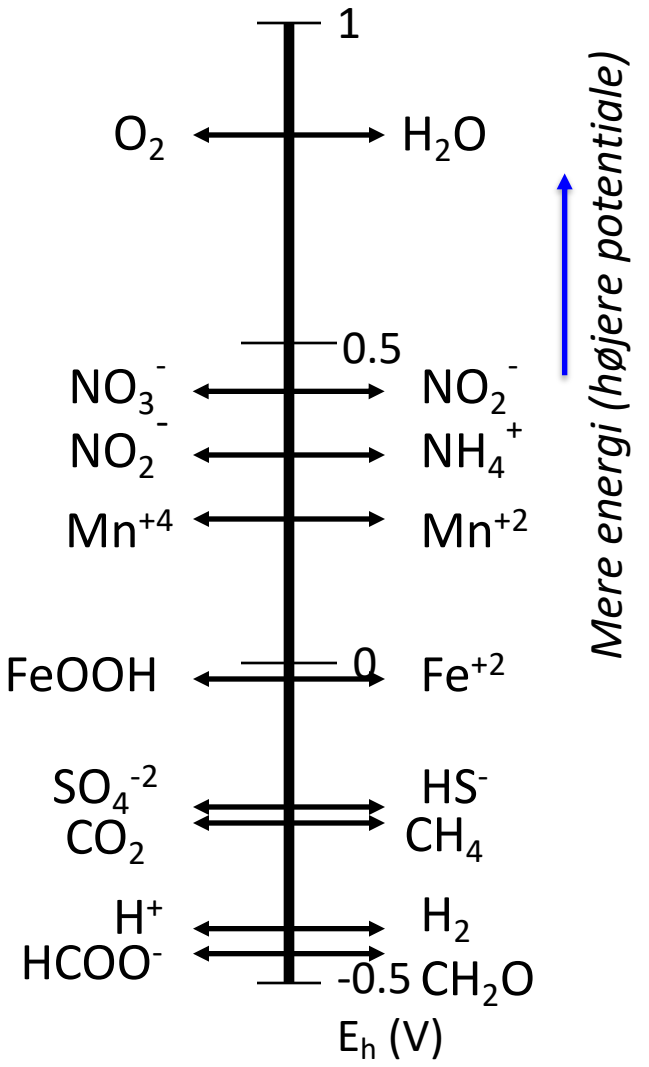
$CH_2O + O_2 \Rightarrow CO_2 + H_2O$





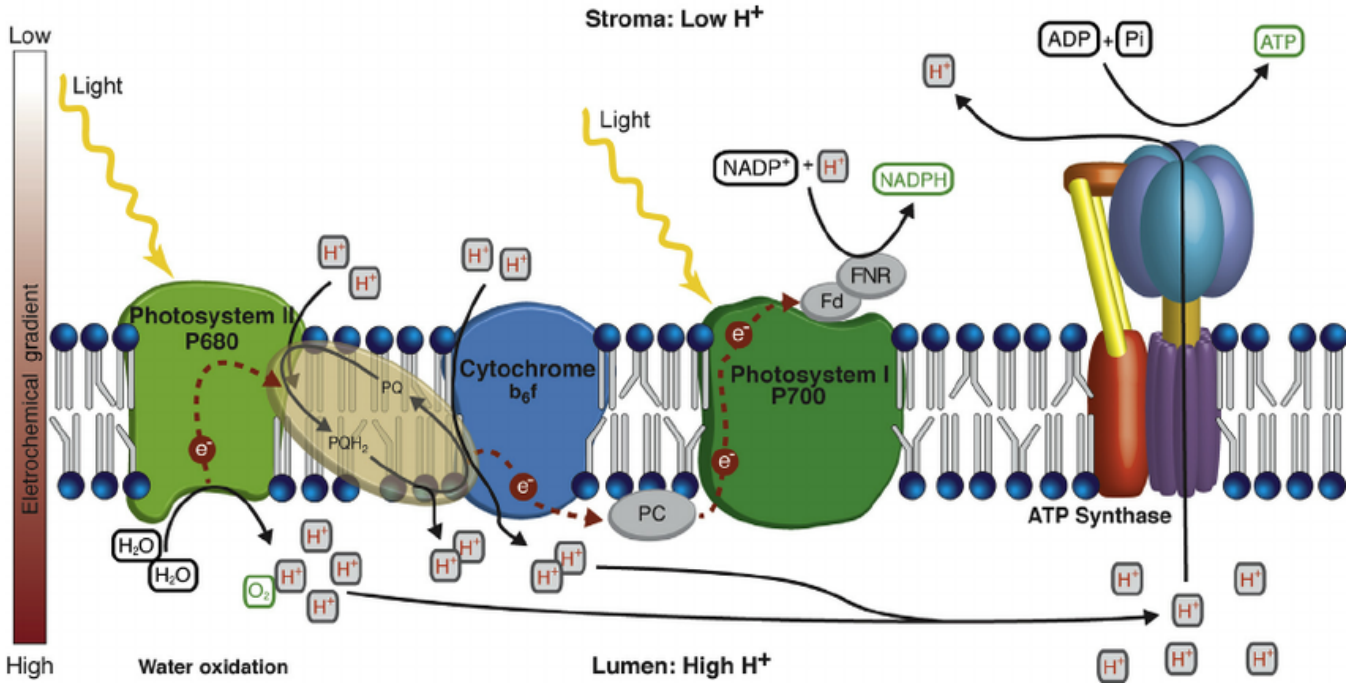
Aerob forbrænding (med ilt)

$$CH_2O + O_2 \Rightarrow CO_2 + H_2O$$



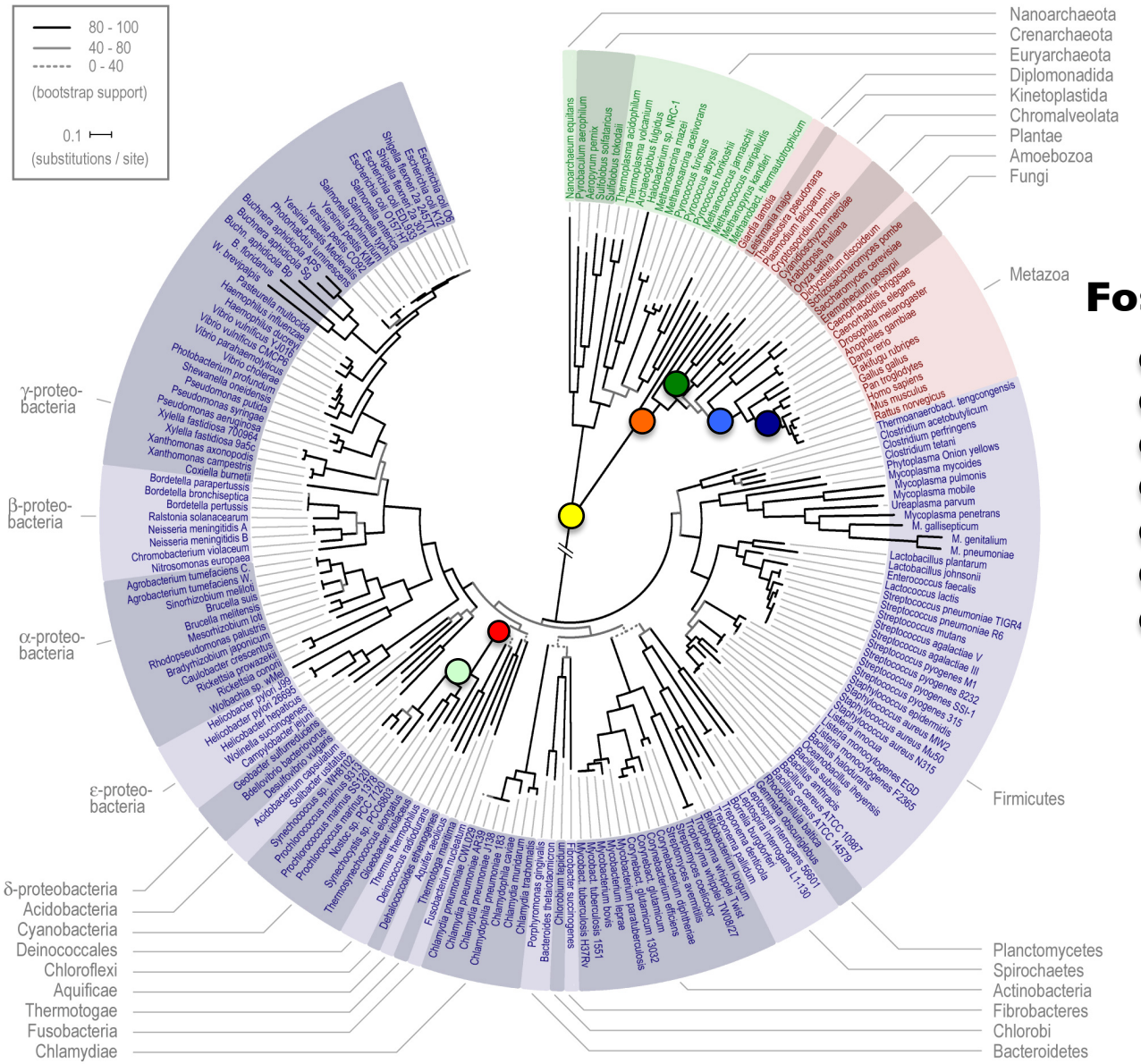
Aerob fotosyntese (med ilt)

$CO_2 + H_2O + lys \rightarrow CH_2O + O_2$



Hvad var det første liv?

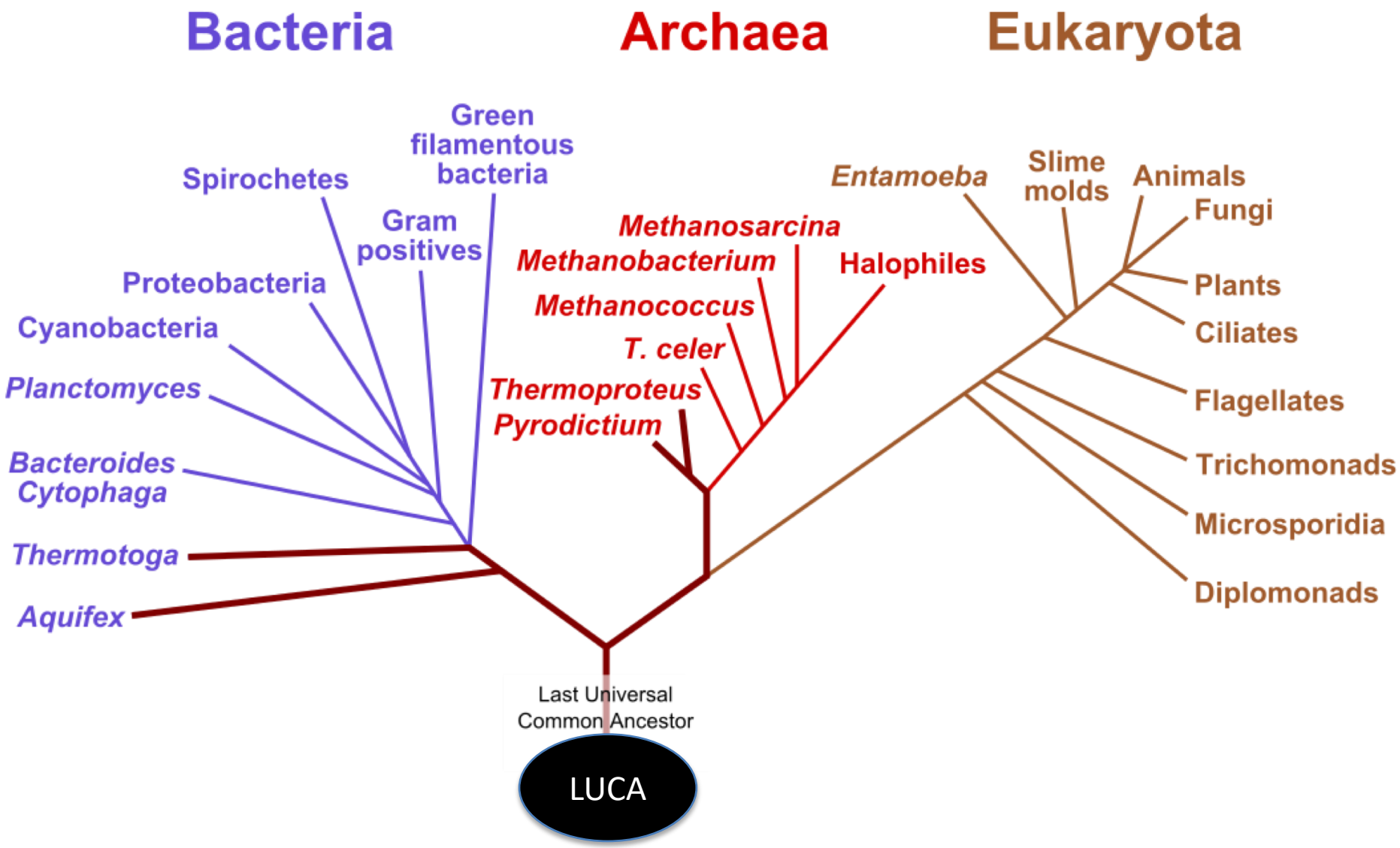
Livets træ

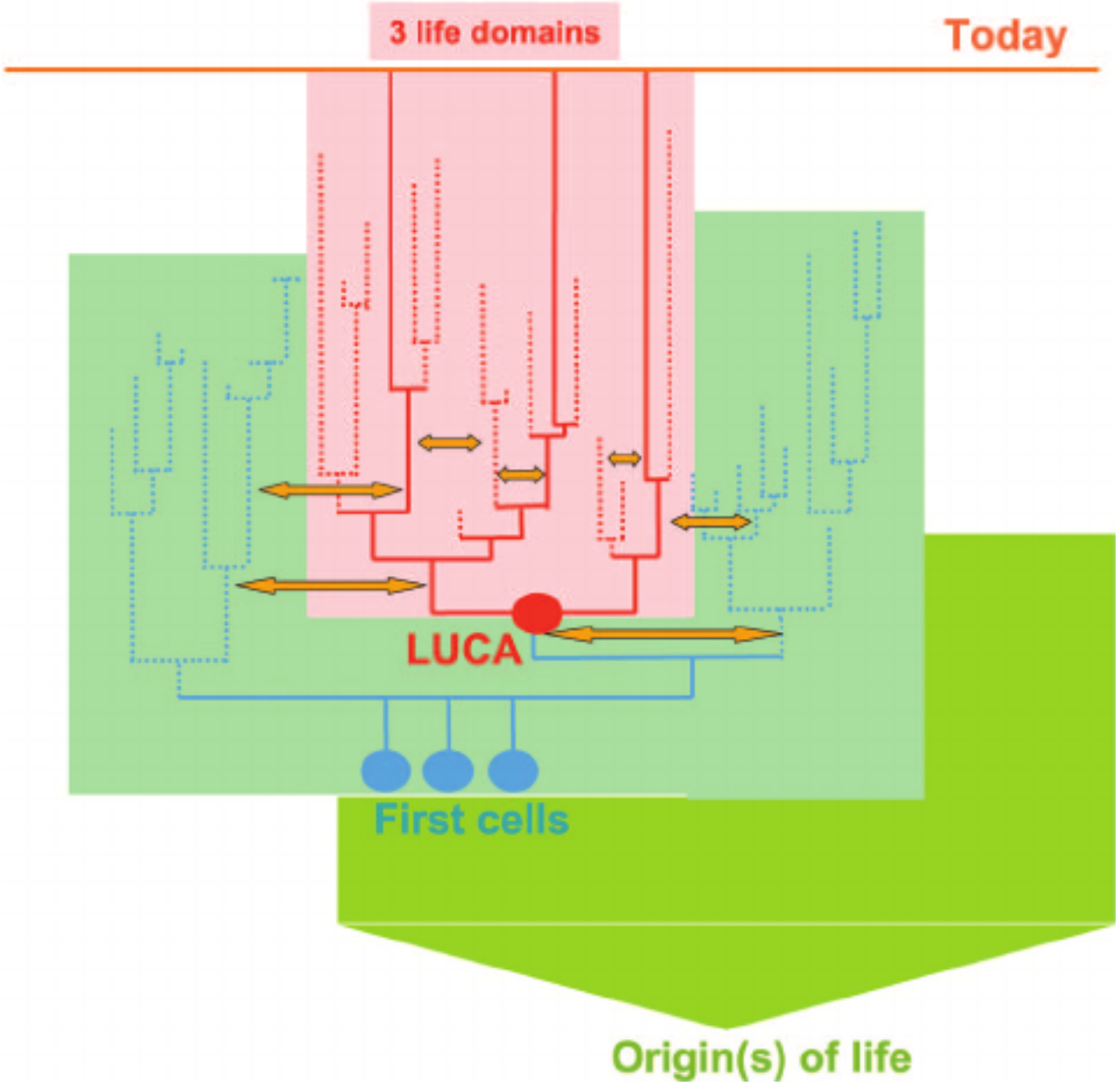


Fossilerne fortæller os

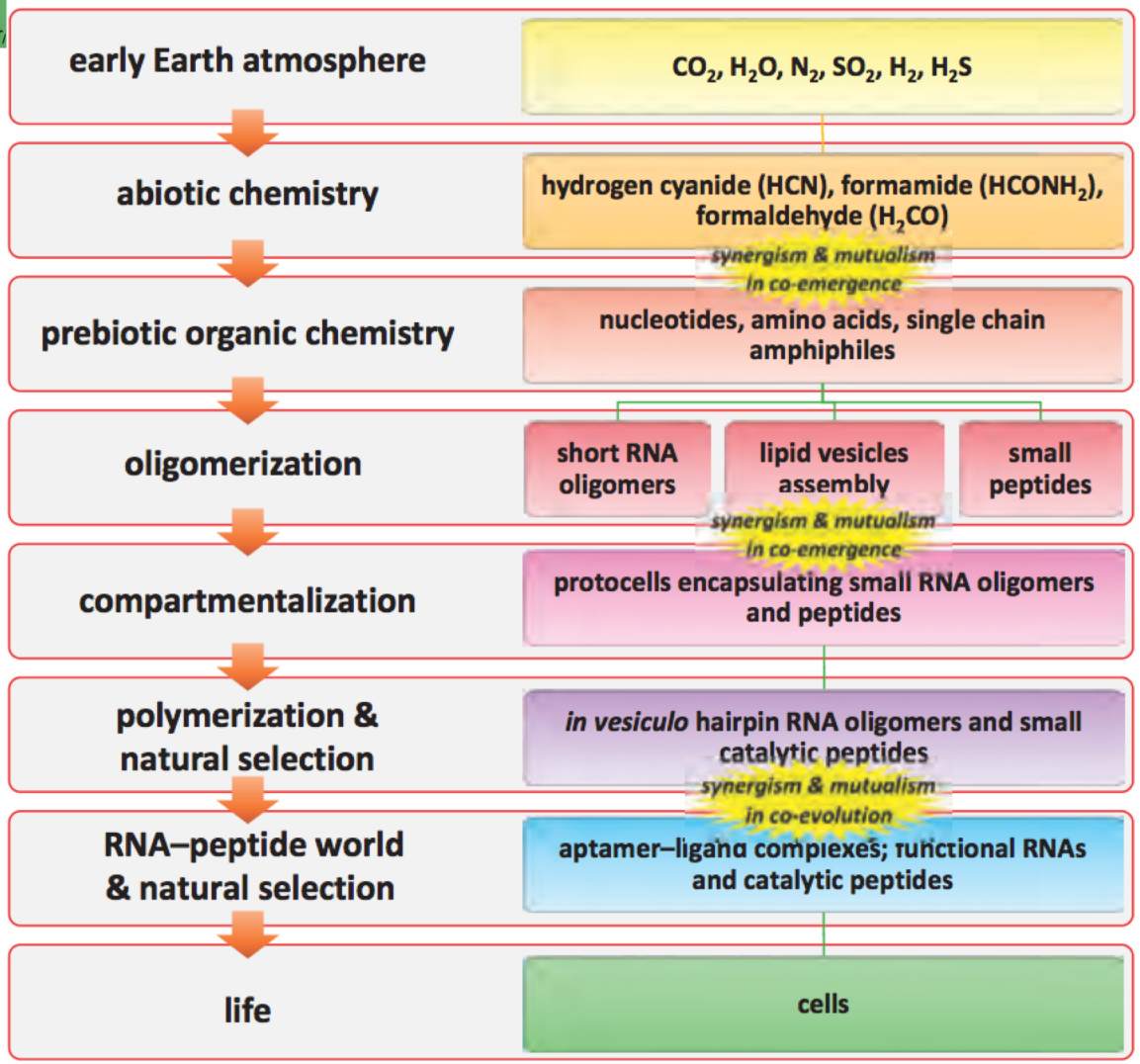
- >3800 Ma Første celler
- >2500 Ma Cyanobakterier
- >2670 Ma Eukaryote celler
- >1500 Ma
- >1200 Ma Akvatiske planter
- > 635 Ma Dyr
- ~ 410 Ma Tetrapoder

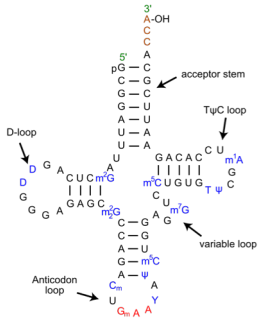
Livets træ (slægtskab)




3 life domains
Today
LUCA
First cells
Origin(s) of life

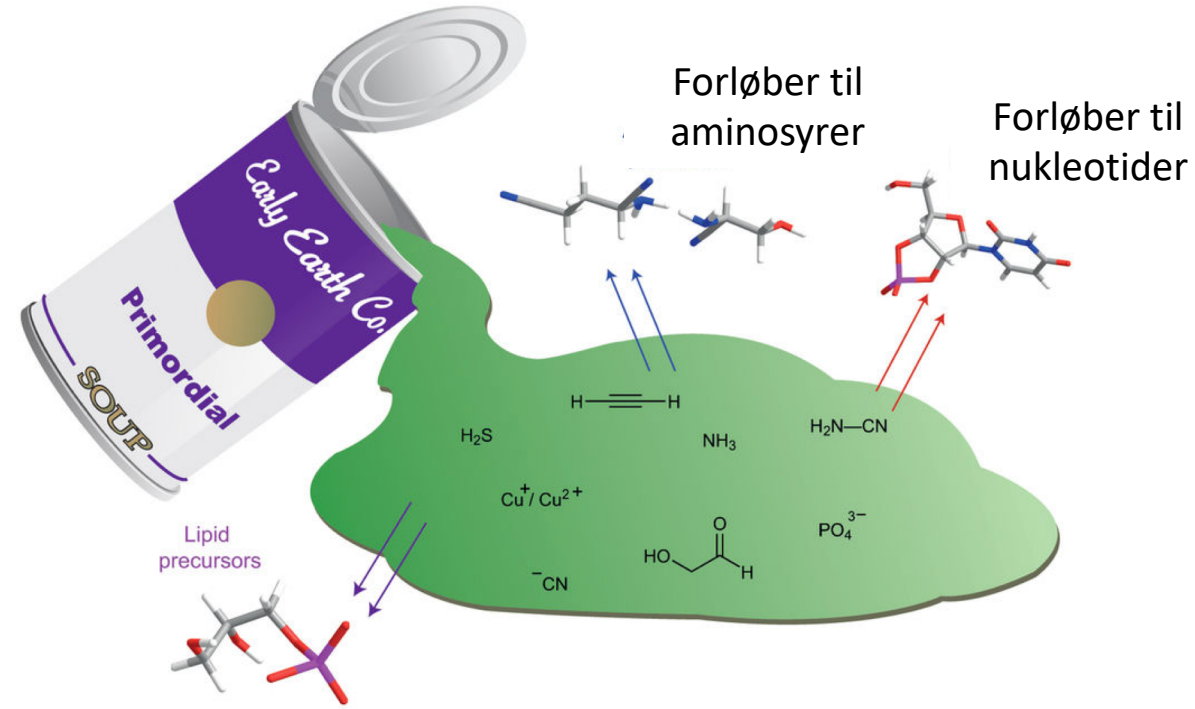
Livets opståen





LUCA

Hvor kommer livets byggesten fra?

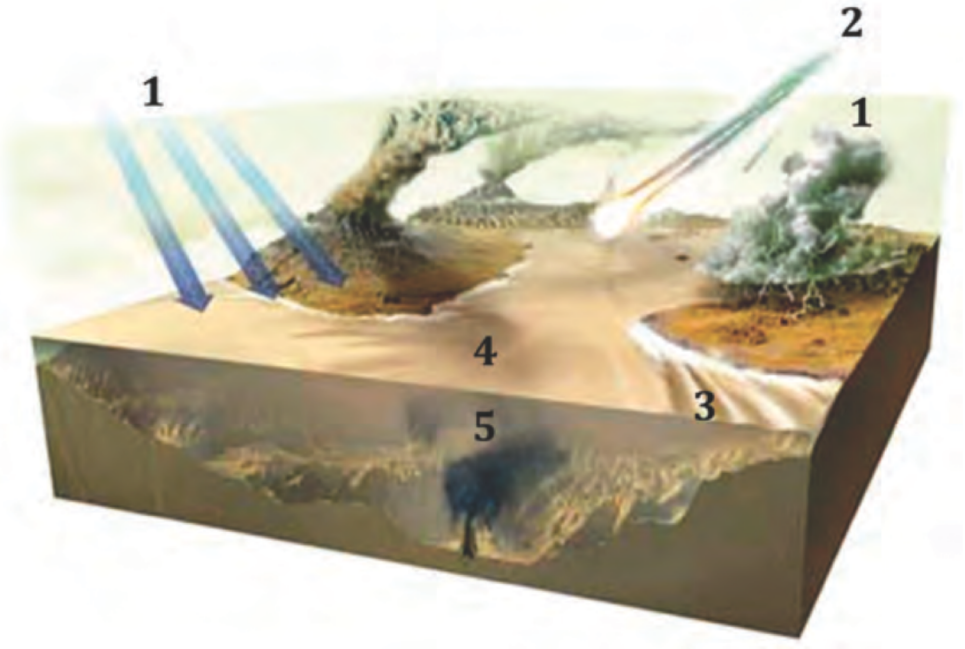


Forløber til aminosyrer

Forløber til nukleotider

Forløber til fedtsyrer

5 miljøer hvor præbiotiske organiske molekyler kunne komme fra

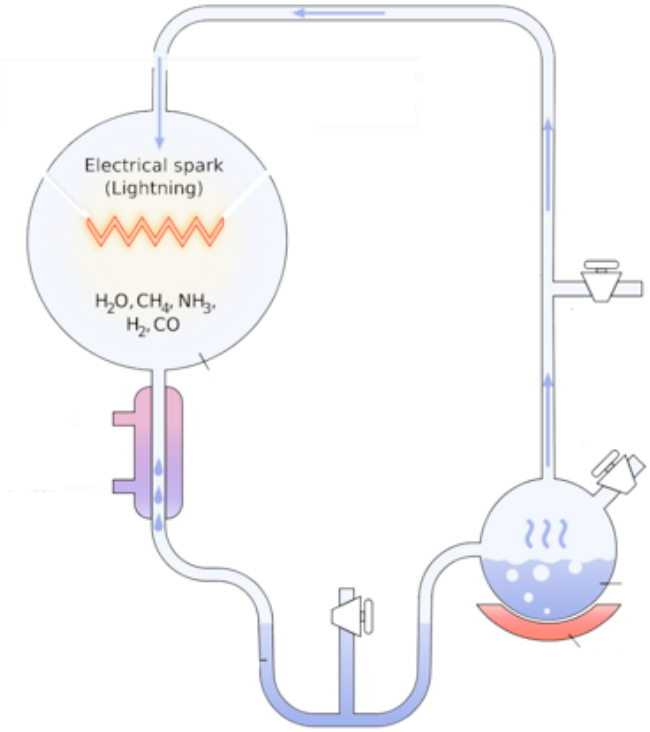


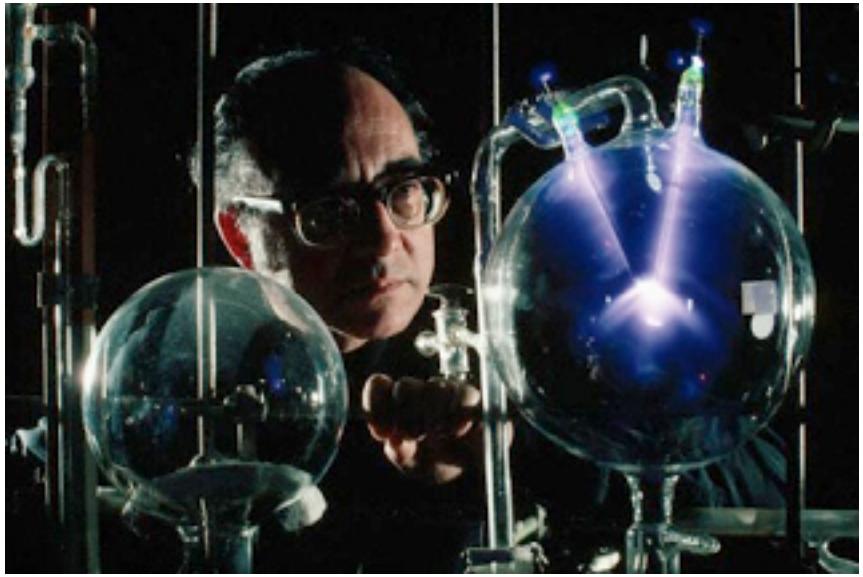
1 Atmosfæren
2 Meteoritter og kometer
3 Overflader mellem mineraler og vandig opløsning (med sollys)
4 Overflader mellem mineraler og vandig opløsning (uden sollys)

5 Varme kilder og under overfladen

Urey-Miller experimentet

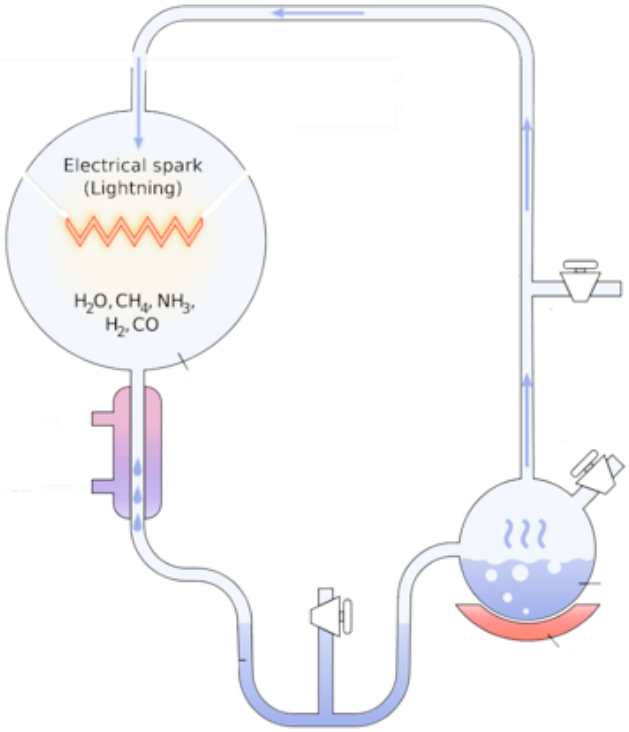
University of Chicago 1953

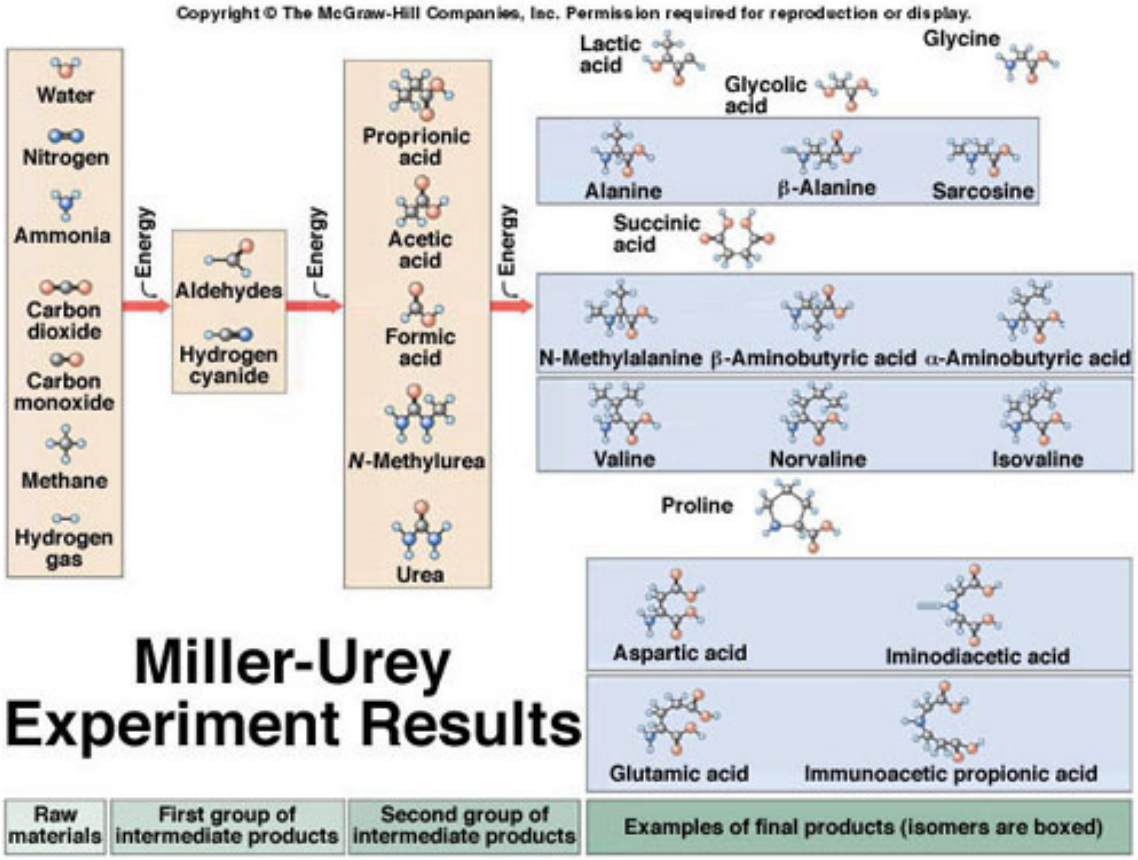


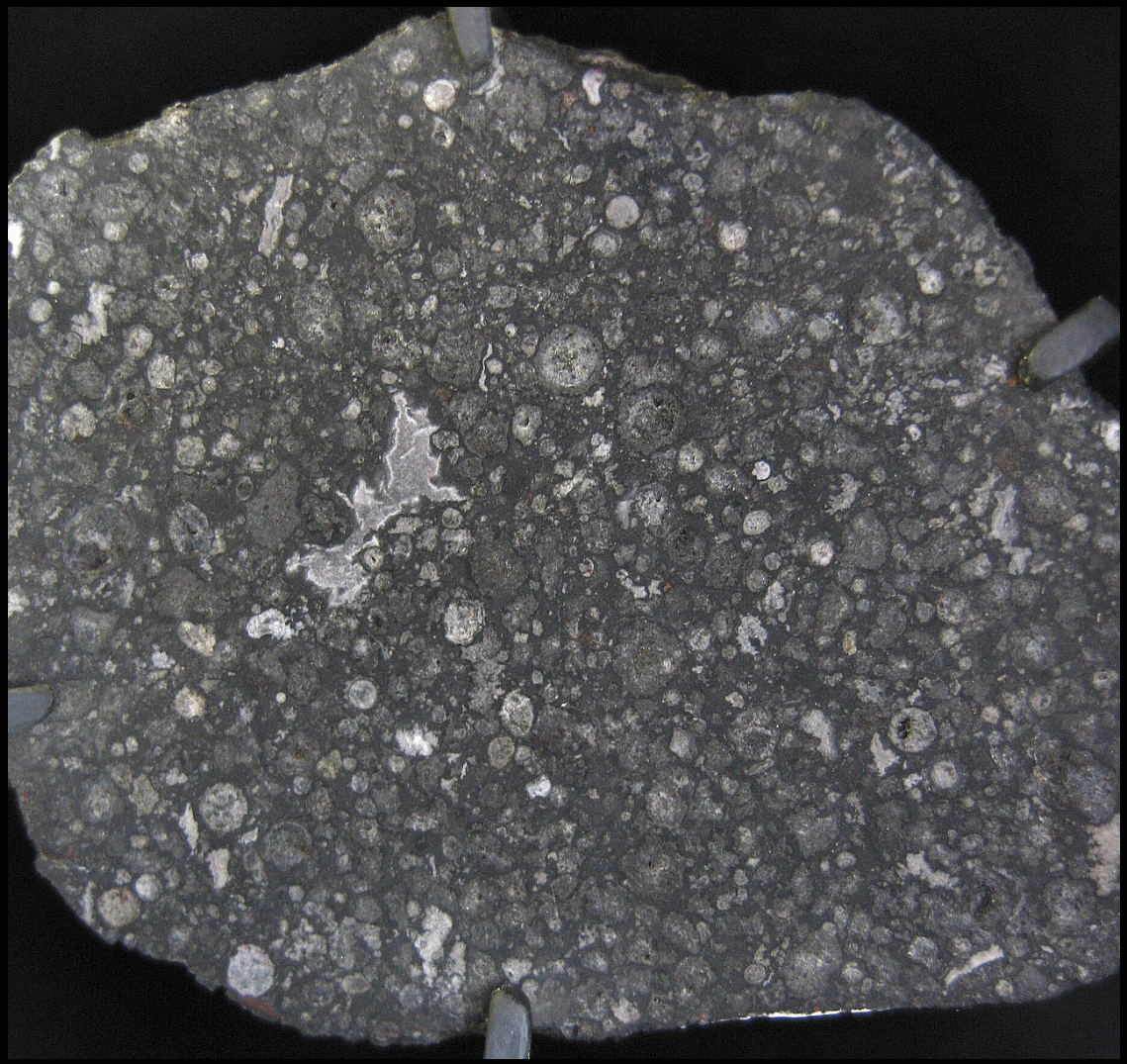


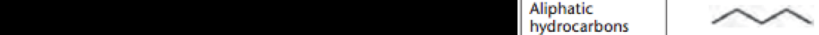
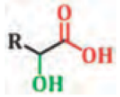
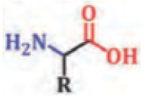
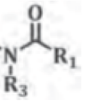
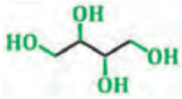
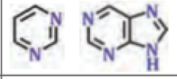
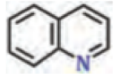
Urey-Miller experimentet

University of Chicago 1953



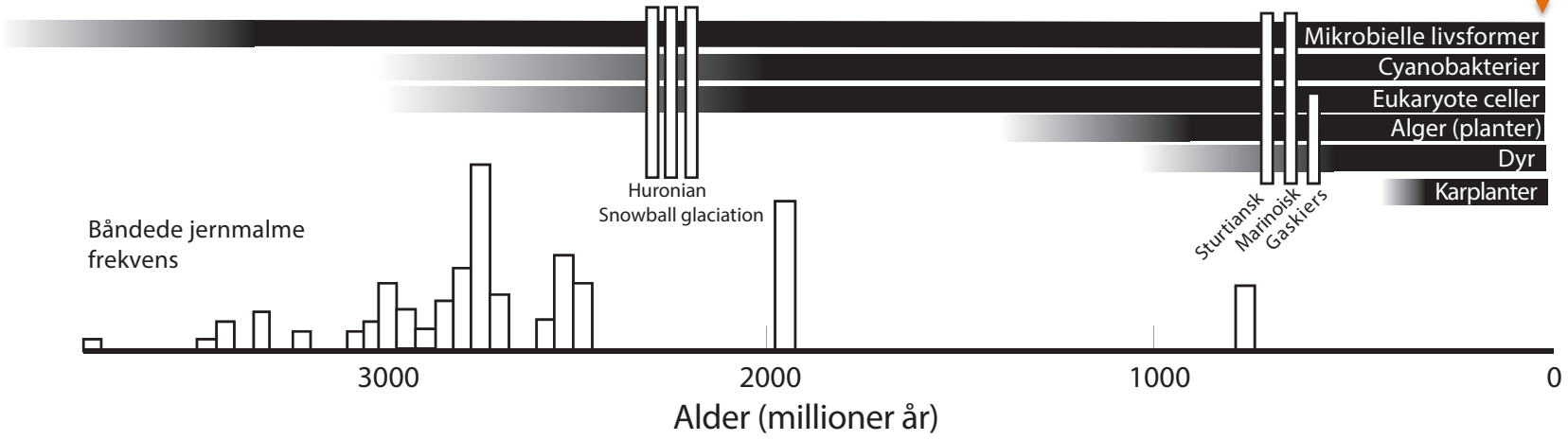




Compounds	Structure	Concentration (ppm)	Carbon Chain Length
Aliphatic hydrocarbons		12–35	C1–C30
Aromatic hydrocarbons		15–28	C6–C20
Carboxylic acids		>350	C1–C12
α-Hydroxy carboxylic acids		15	C2–C8
Alcohols		11	C1–C4
Aldehydes		11	C1–C5
Ketones		16	C1–C5
Amines		8	C1–C4
Amino acids		60	C2–C9
Amides		62	C1–C3
Sugar-related (sugar alcohols, sugar acids)		60	C3–C6
Purines and Pyrimidines		2	C4–C5
Basic N-heterocycles		0.05–0.5	C4–C5
Sulfonic acids		67	C1–C4
Phosphonic acids		1.5	C1–C4
Polymers (macromolecular compounds)	—	>14,300	C>100

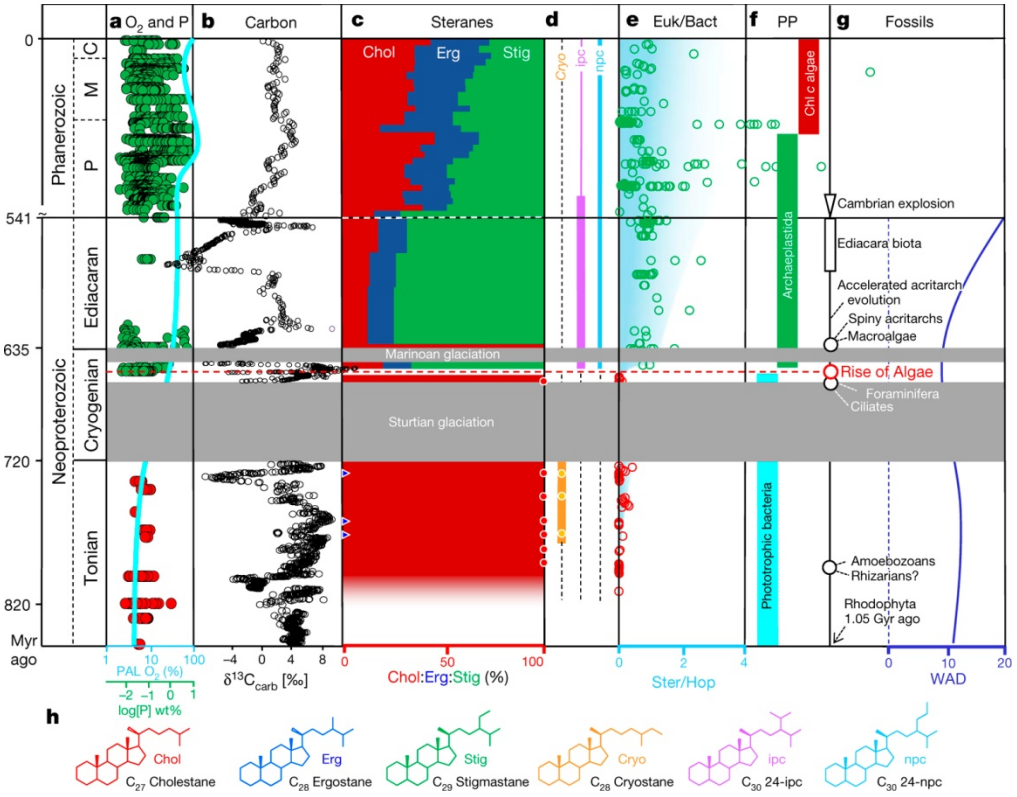
After Sephton (2002) and Llorca (2004).

Hvorfor opstod mennesker og dyr så sent?



Hvorfor opstod dyr så sent?

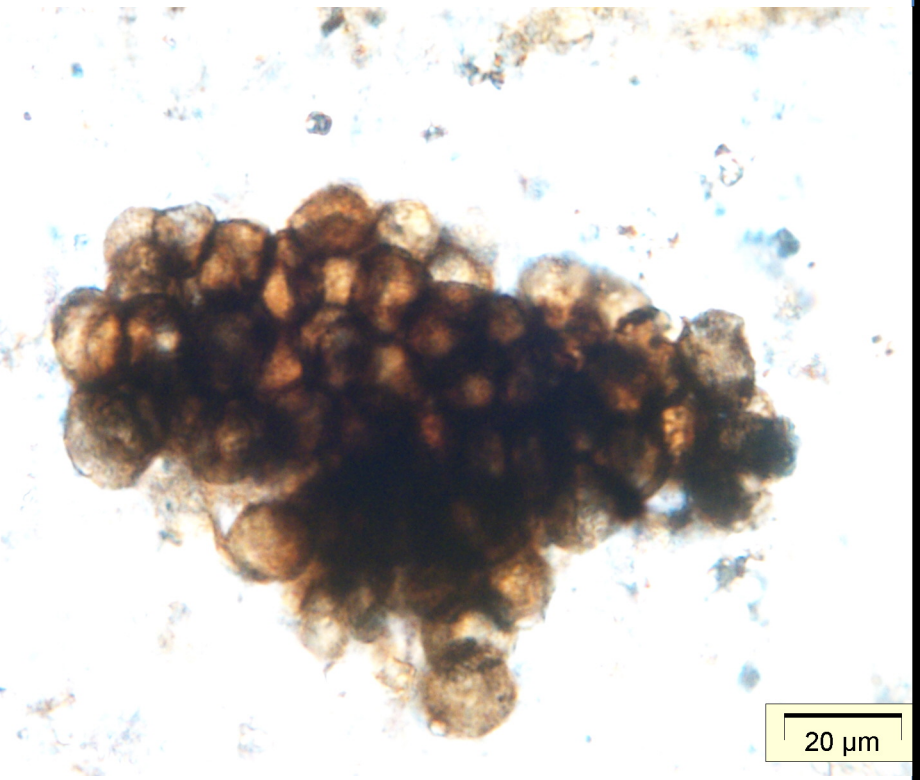
Brocks et al 2017: “Madpakkerne blev større”
Selv om algerne udviklede sig tidligere, var det først efter den Sturtianske istid (~650 Ma) at algerne begyndte at dominere over cyanobakterier i havet…



J J Brocks *et al. Nature* 1–4 (2017) doi:10.1038/nature23457

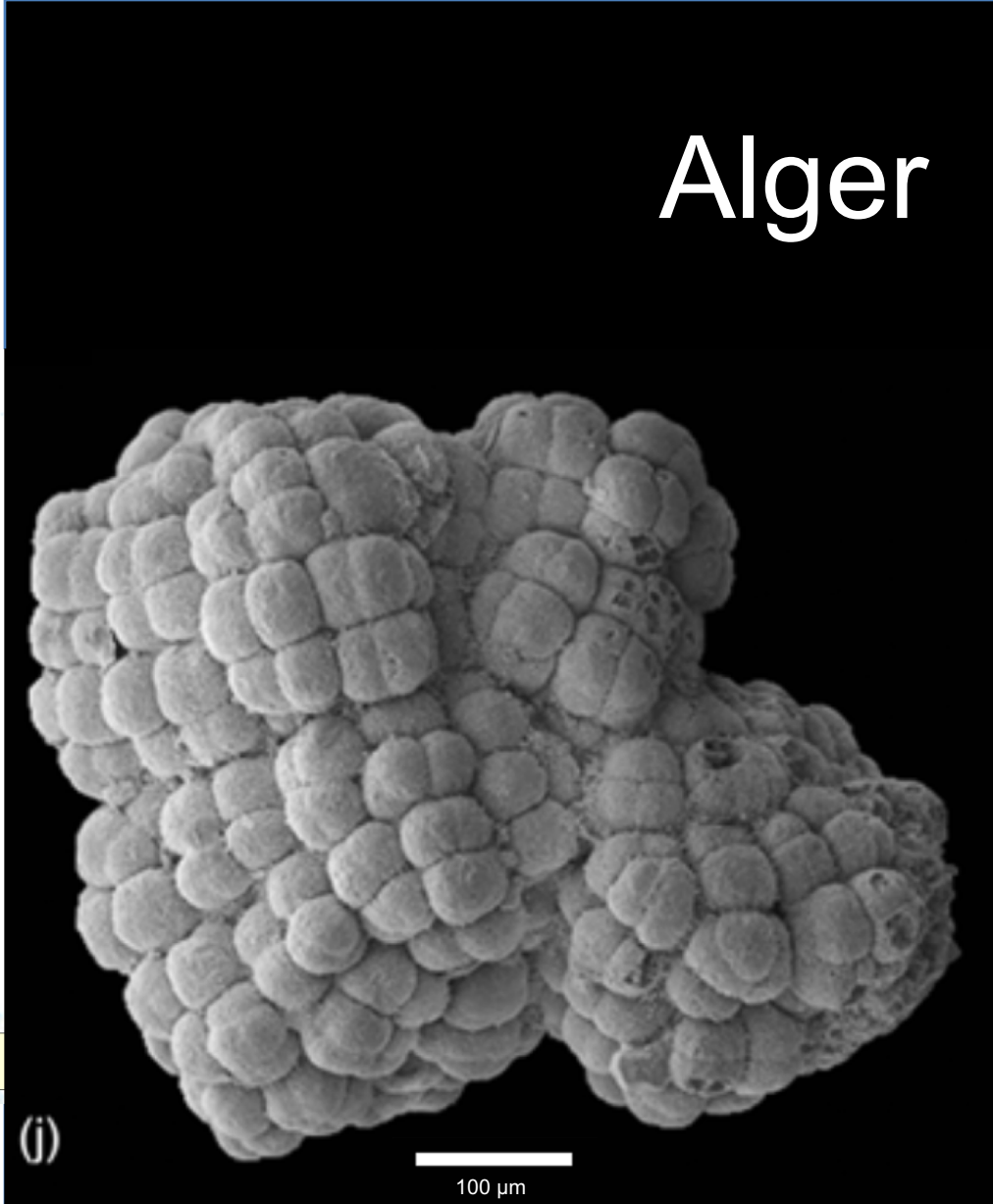
nature

Cyanobakterier



Myxococcoides cantabrigiens
cyanobakterier
Draken Formationen, Svalbard
~800 mio. år gammel
Foto: T. W. Dahl

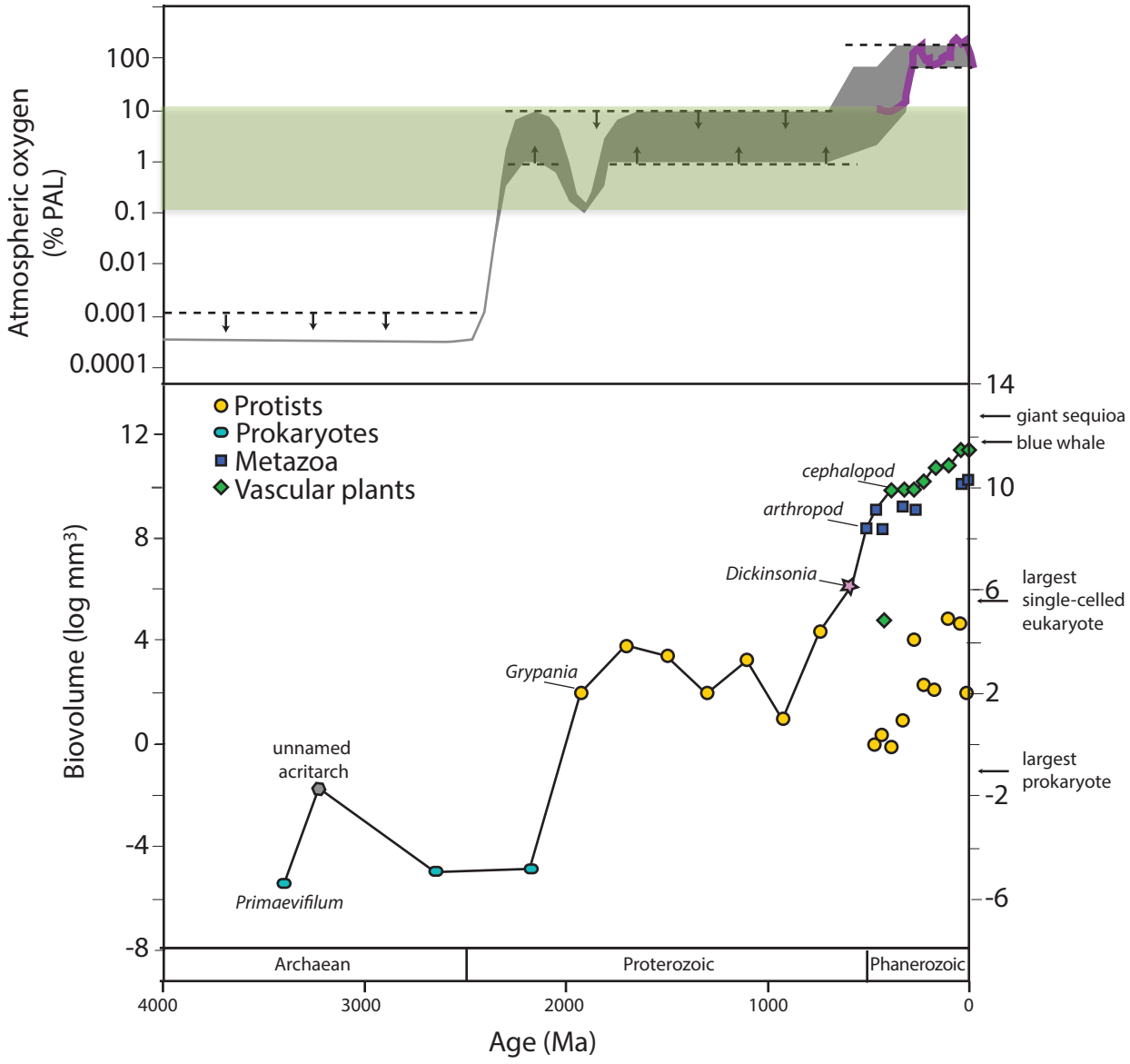
Alger



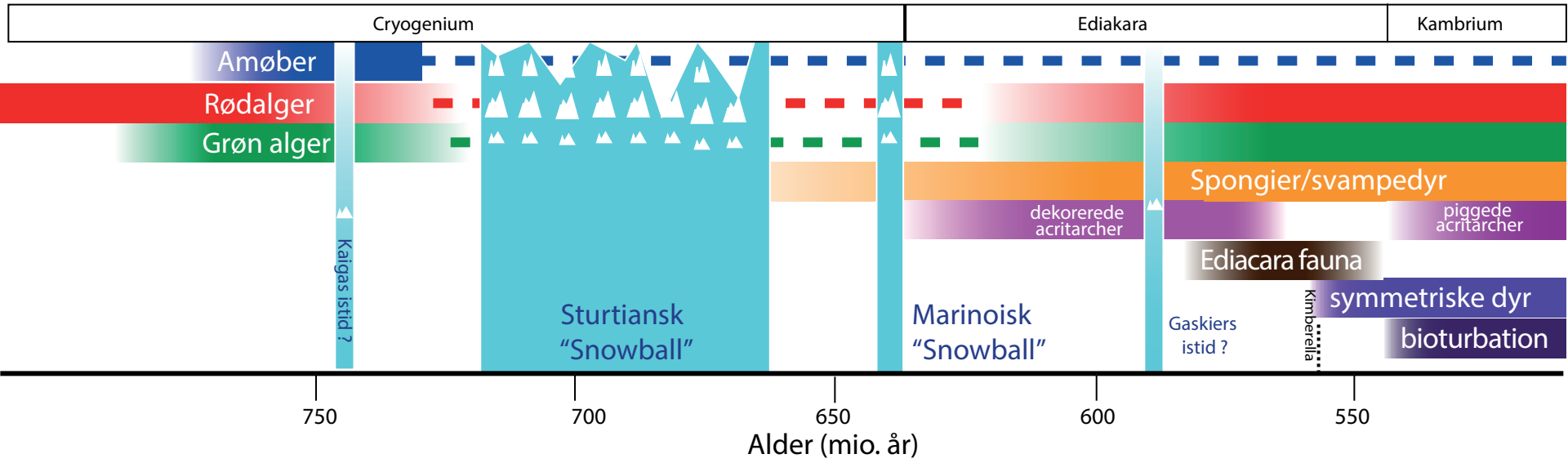
Archaeophycus
Mulig rødalge
Weng'an Biota, Kina· 609-570 mio år gammel
Cunningham et al. 2017

Livets udvikling er tæt knyttet til fri ilt

O_2


Atmospheric oxygen (% PAL)
100
10
1
0.1
0.01
0.001
0.0001
Protists
Prokaryotes
Metazoa
Vascular plants
Biovolume (log mm³)
12
8
4
0
-4
-8
14
10
6
2
-2
-6
giant sequioa
blue whale
largest single-celled eukaryote
largest prokaryote
cephalopod
arthropod
Dickinsonia
Grypania
unnamed acritarch
Primaevifilum
Archaean
Proterozoic
Phanerozoic
4000
3000
2000
1000
0
Age (Ma)

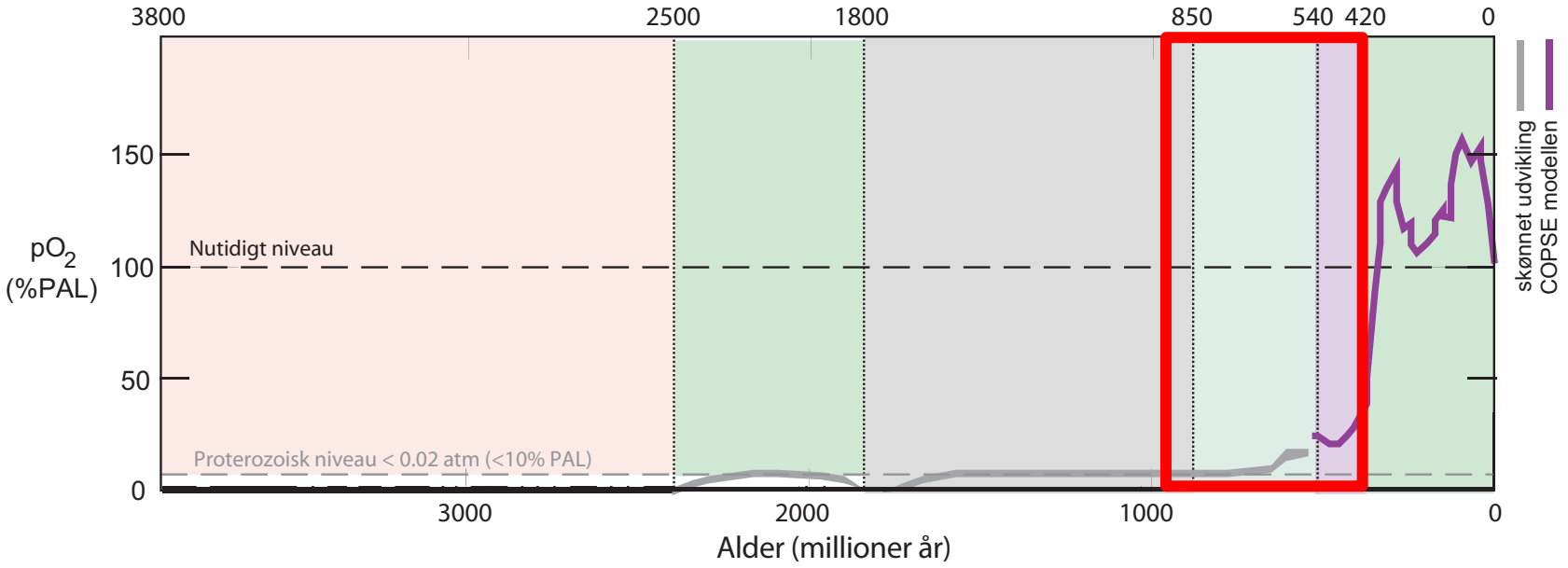
Dyrenes tidlige udviklingshistorie



tid

O_2 ➔ dyr


ARC'TERYX

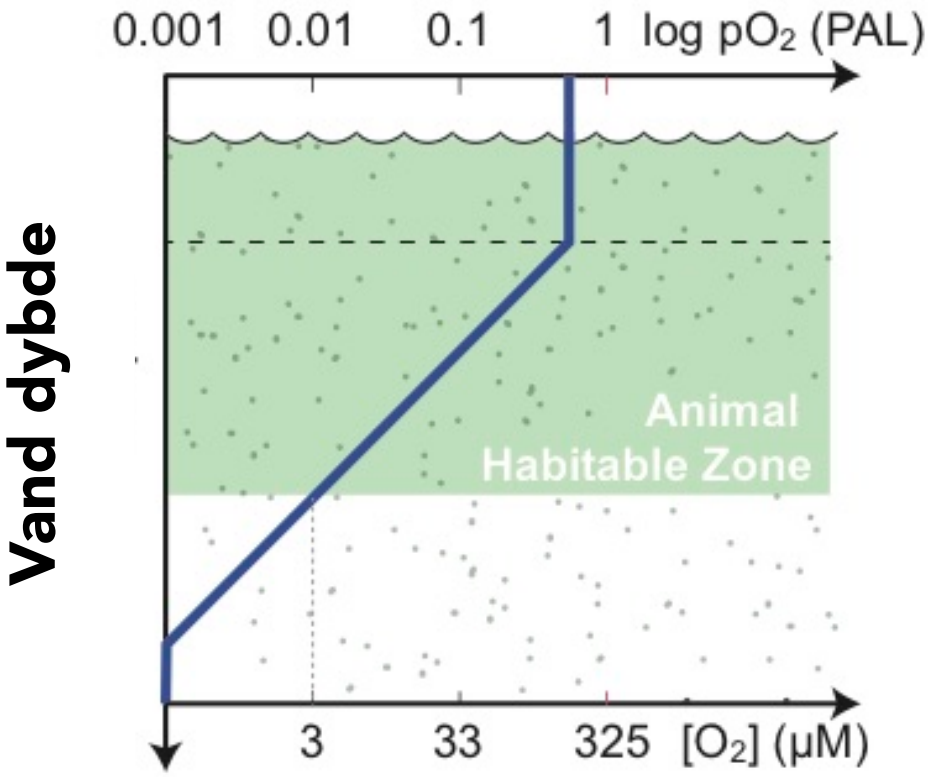

3800
2500
1800
850
540
420
0
150
100
50
0
pO2
(%PAL)
Nutidigt niveau
Proterozoisk niveau < 0.02 atm (<10% PAL)
3000
2000
1000
0
Alder (millioner år)
skønnet udvikling
COPSE modellen

dyr ➔ O_2

Dyrene påvirker miljøet og stabiliserer iltniveauet ved at regulere kulstofkredsløbet på Jorden

(bl.a. via bioturbation og fækalieperler)

Ilt indhold



555 mio. år siden

Dahl et al. *Geochemical Perspectives Letters* 2017

nature geoscience

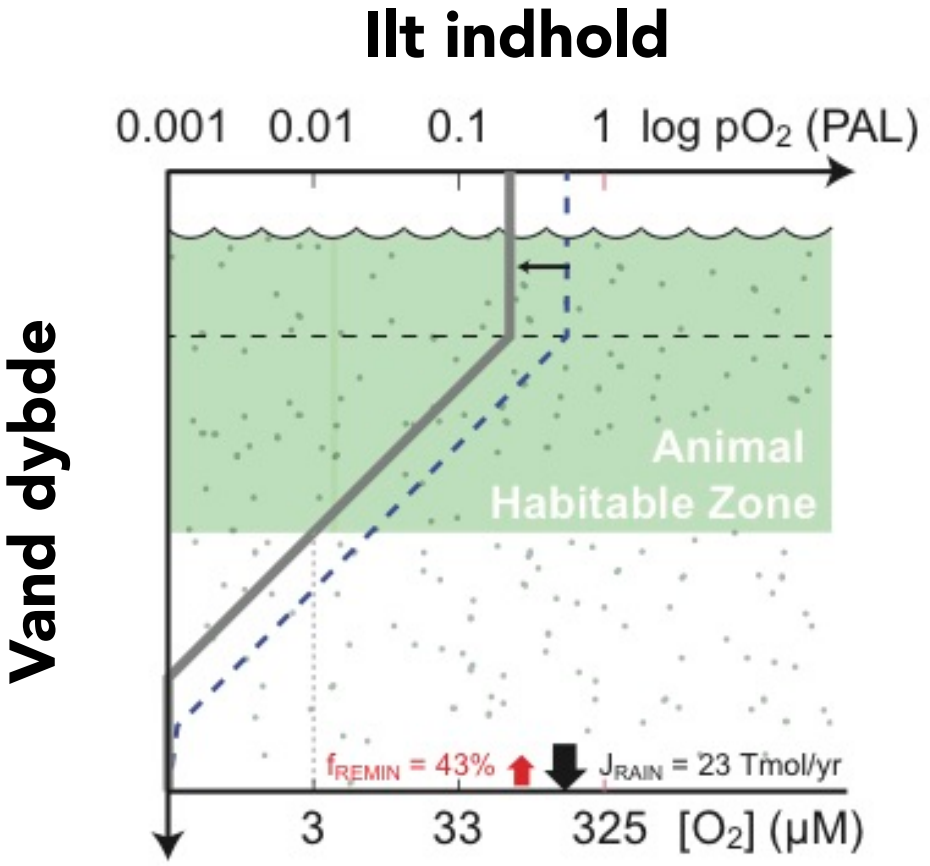
LETTERS

PUBLISHED ONLINE: 3 AUGUST 2014 | DOI: 10.1038/NGEO2213

Stabilization of the coupled oxygen and phosphorus cycles by the evolution of bioturbation

R. A. Boyle[1,2*], T. W. Dahl[1,3], A. W. Dale[4], G. A. Shields-Zhou[5], M. Zhu[6], M. D. Brasier[7], D. E. Canfield[1] and T. M. Lenton[2]

Orme graver i mudder · hermed begraves næringstoffet P · produktivitet og O_2 hæmmes



525 mio. år siden

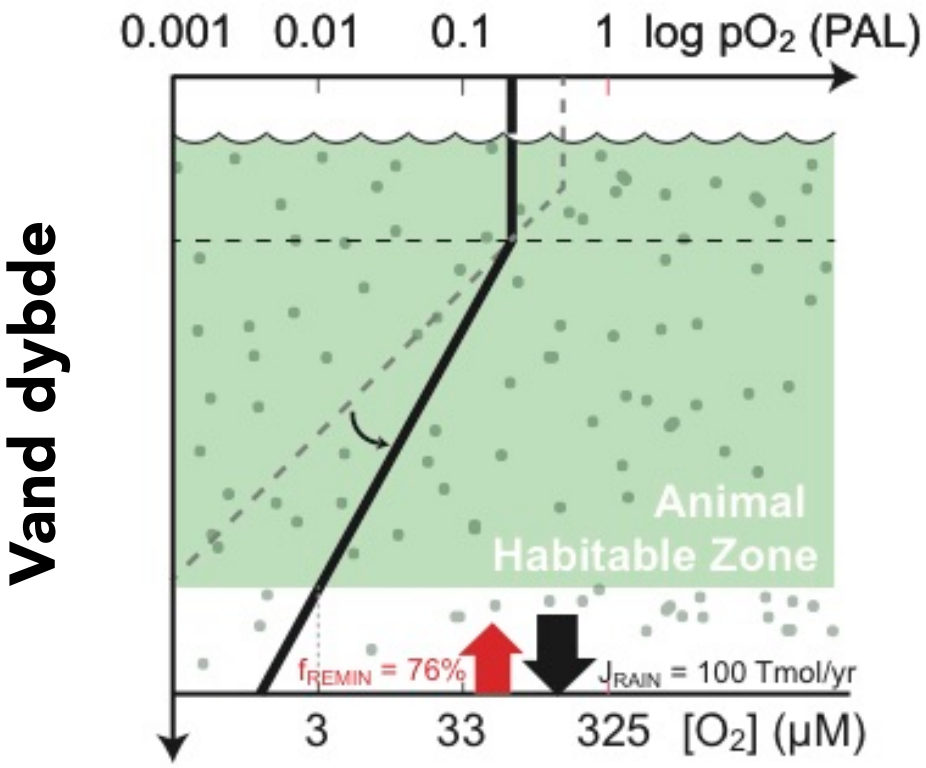
Boyle, Dahl et al. (2014) *Nature Geo. 7:671-676*

Isoxys (zooplankton) op til 45 mm lang

Logan et al. *Nature* 1995
Lenton et al. *Nature Geoscience* 2014
Dahl et al. *Geochemical Perspectives Letters* 2017

Større dyr (meso- og makro-zooplankton) · større fækalieperler
· organisk materiale synker hurtigere til bunds
· mindre O_2 forbrug i vandsøjlen · den O_2–holdige zone expanderede

Ilt indhold

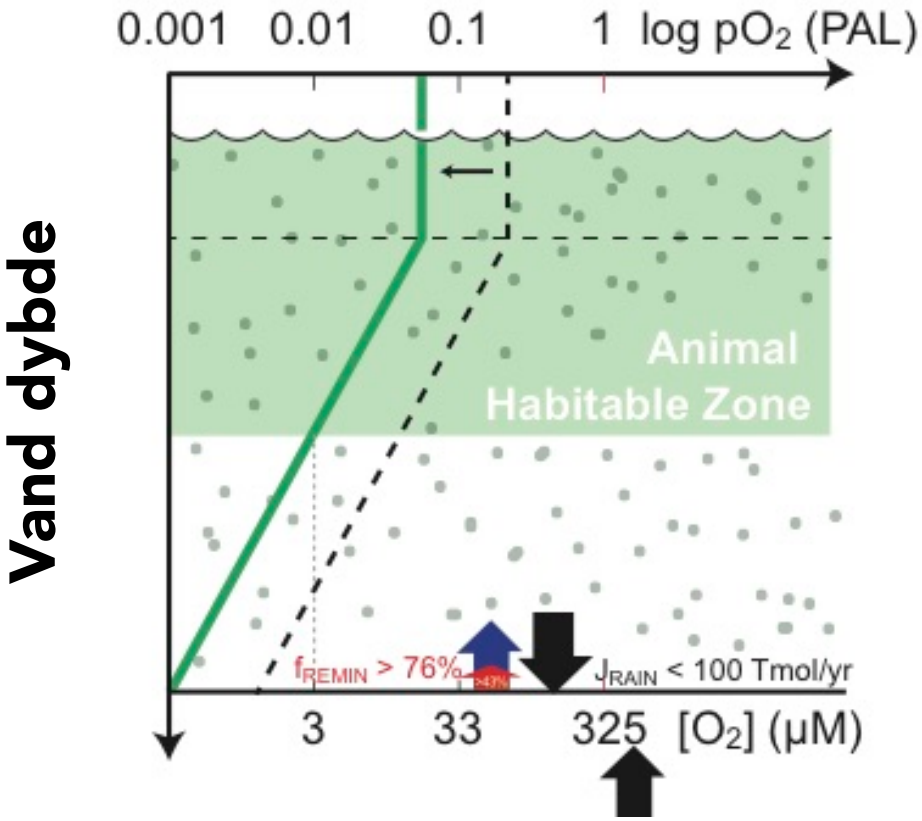


521 mio. år siden

Dahl et al. *Geochemical Perspectives Letters* 2017

Føden blev flyttet til bunden af havet · flere orme graver i mudder
Orme graver i mudder · hermed begraves næringstoffet P · produktivitet og O_2 hæmmes

Ilt indhold



520 mio. år siden

Dahl et al. *Geochemical Perspectives Letters* 2017

Dyrene påvirker miljøet og stabiliserer iltniveauet
ved at regulere kulstofkredsløbet på Jorden (bl.a. via bioturbation og fækalieperler)

Sammenfatning

- Livet har udviklet sig på Jorden igennem mere end 3,5 mia. år
- Alt liv har en fælles stamfader: LUCA
- Det første liv var mikrobielt.
- Disse celler kunne både replikere og omsætte energi
- Energien fandtes allerede i form af geokemiske reaktioner, der alligevel foregik i miljøet, men cellerne havde enzymer og kunne få reaktionerne til at gå hurtigere.
- Mikrobiel vækst er eksponentiel. Livets kraft er overvældende!
- Affaldsprodukter påvirker nærmiljøet og evolutionen.
- Cyanobakterierne påvirkede endda det globale miljø. De frigav O_2 til havet og atmosfæren.
- Iltniveauet forblev lavt og/eller for ustabilt.
- For 0,55 mia. år siden var der rigeligt ilt i havet og bevægelige dyr opstod.
- Dyrs graven og deres tarmsystem har en effekt på kulstofkredsløbet på Jorden. Det kan have stabiliseret iltniveauet og dermed betingelserne for alt højerestående liv.

Tak for jeres opmærksomhed!

Kontakt info:
Tais W. Dahl:
tais.dahl@ign.ku.dk
GLOBE institute
+45 3532 2356
www.geobiology.dk

Danmarks Grundforskningsfond
Danish National Research Foundation

VILLUM FONDEN

Carlsberg
CARLSBERG FOUNDATION

NSF

Læs:

Hvordan man laver en beboelig planet

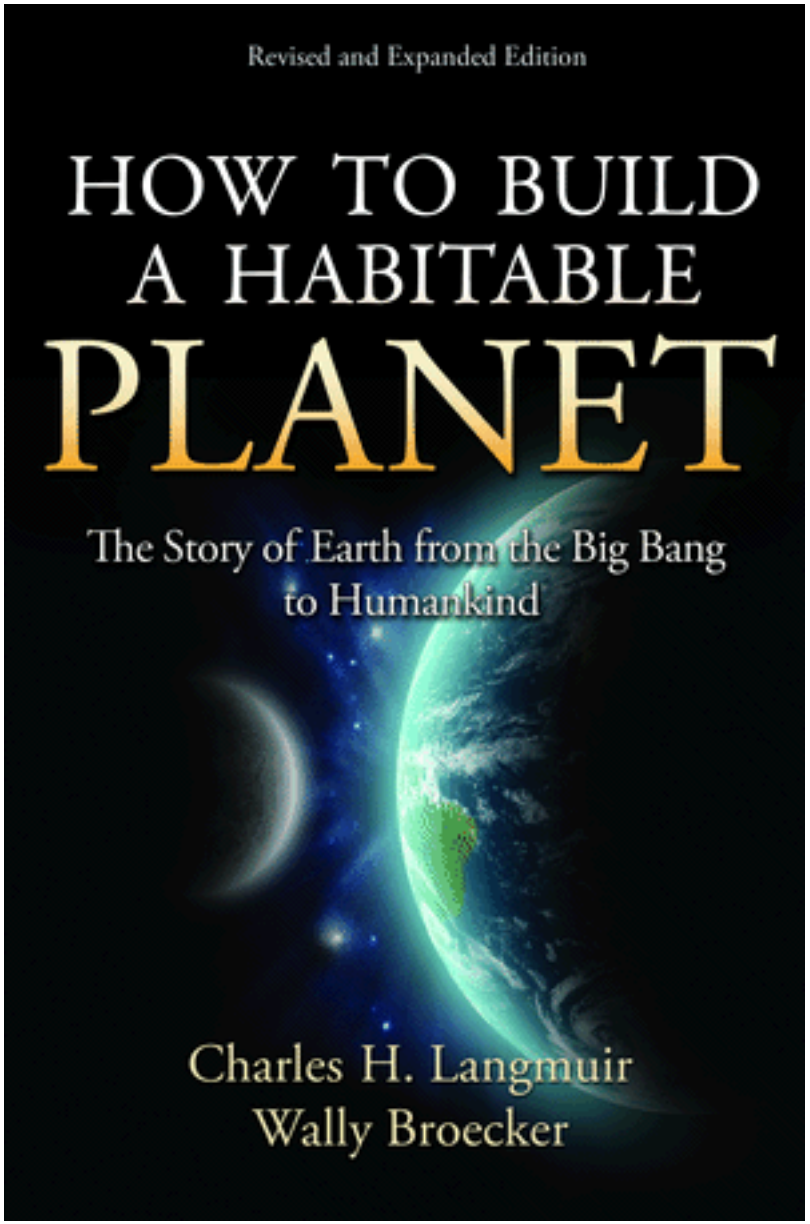
Charles Langmuir

Wally Broecker

2012

Princeton University Press

720 sider



4 August 1972, Volume 177, Number 4047 SCIENCE

More Is Different

Broken symmetry and the nature of the hierarchical structure of science.

P. W. Anderson