UdPPC Brest 2024

À la recherche des premières traces de vie sur Terre

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UBO université de bretagne occidentale

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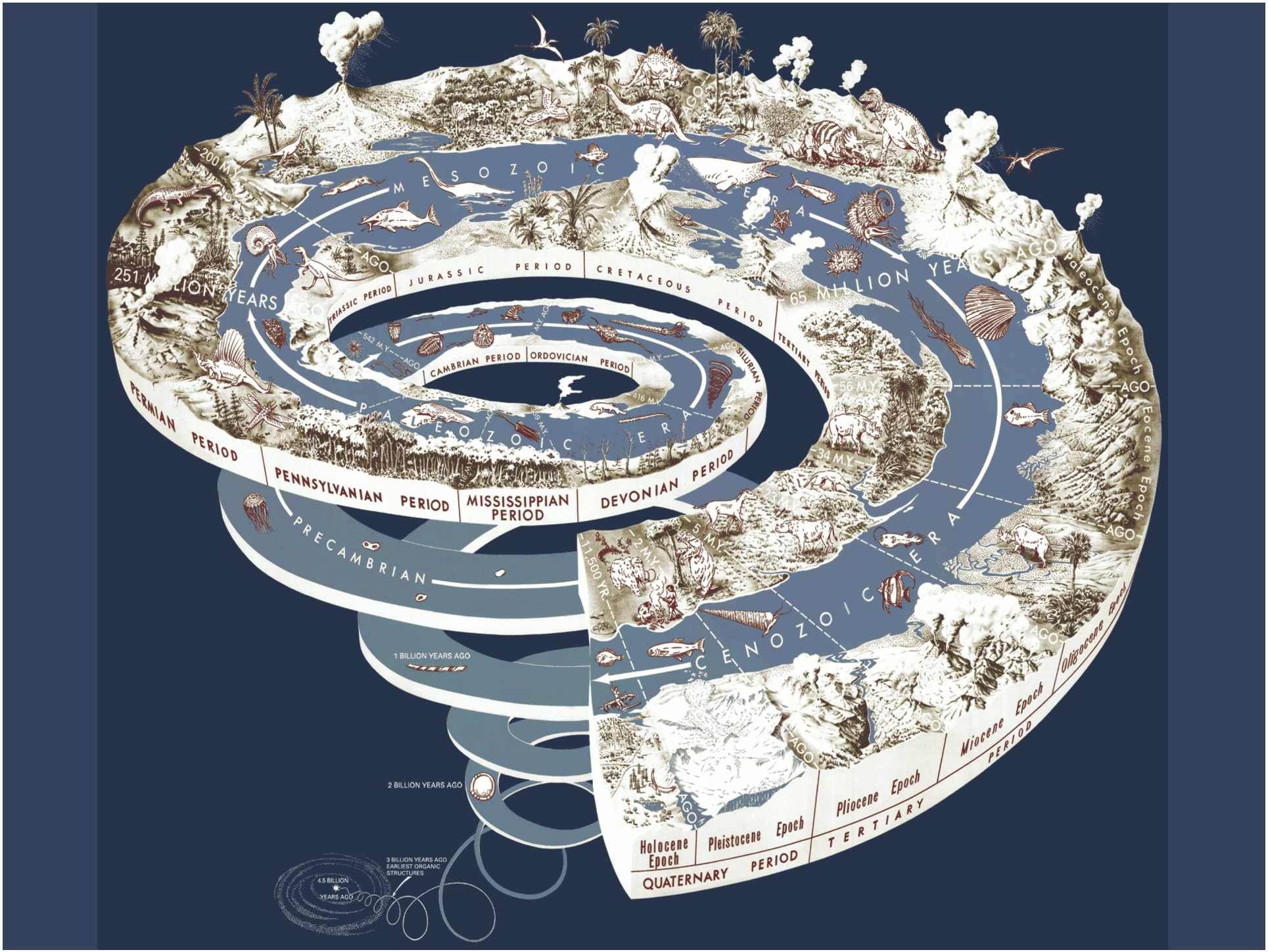
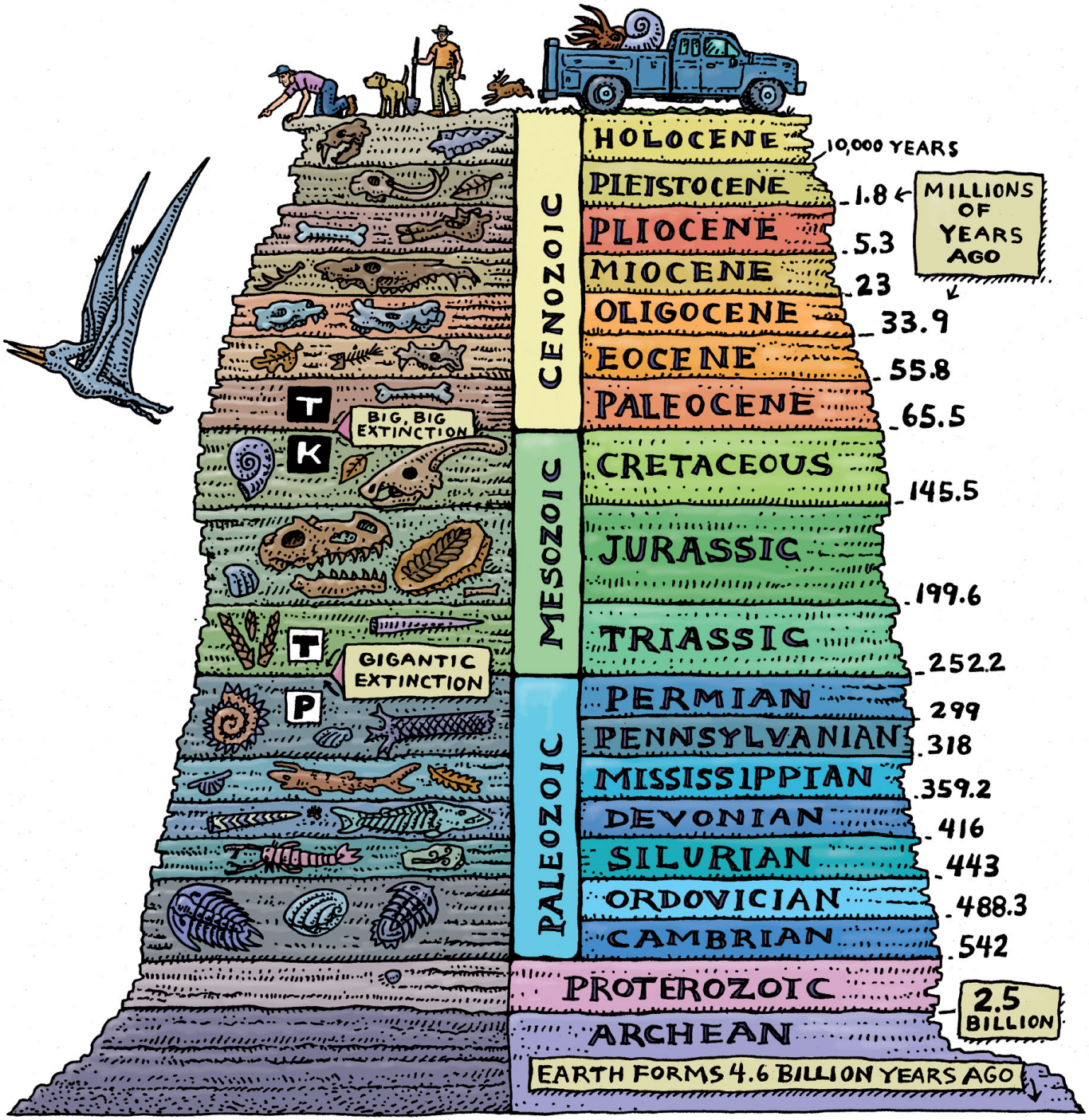
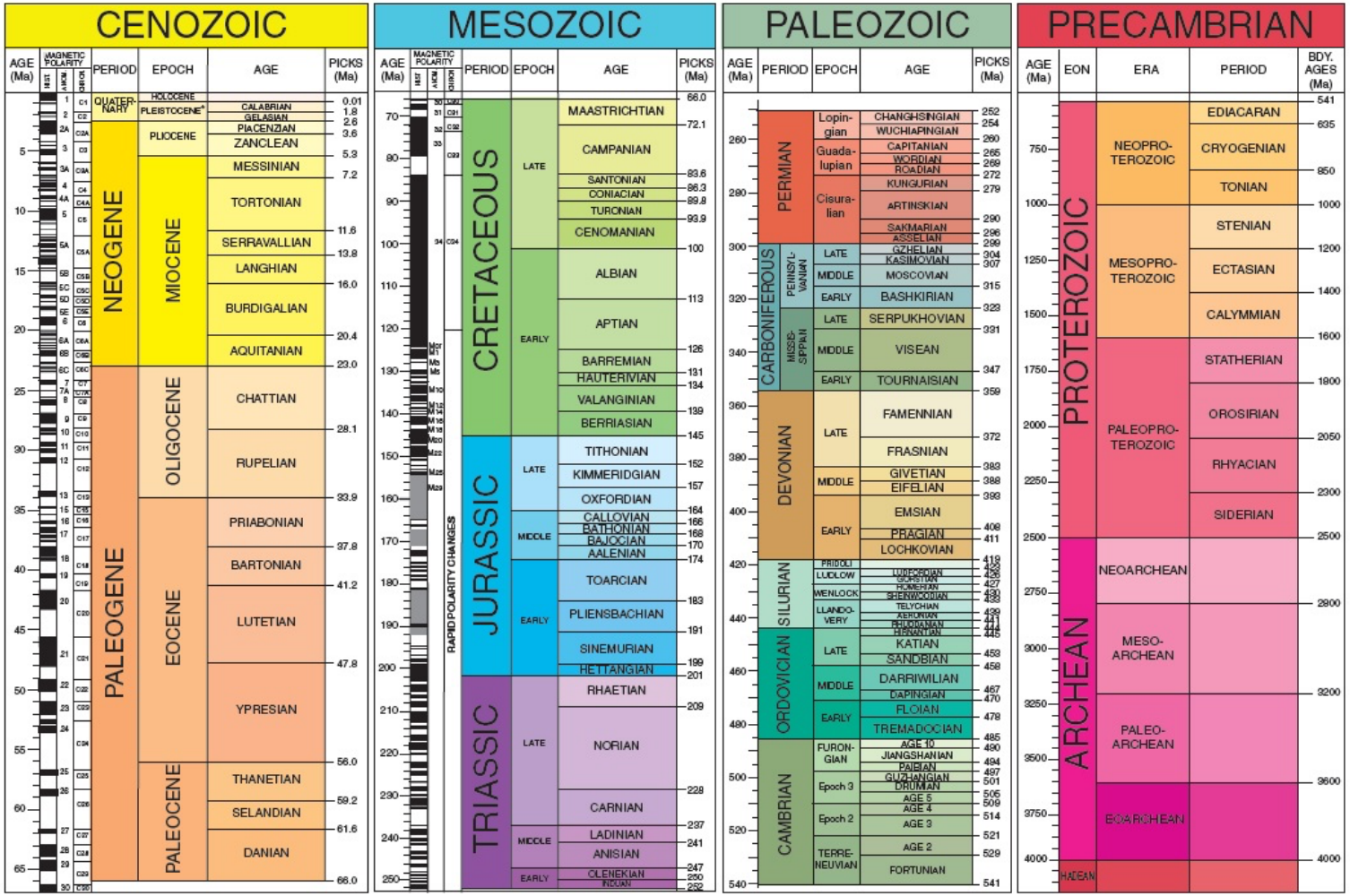
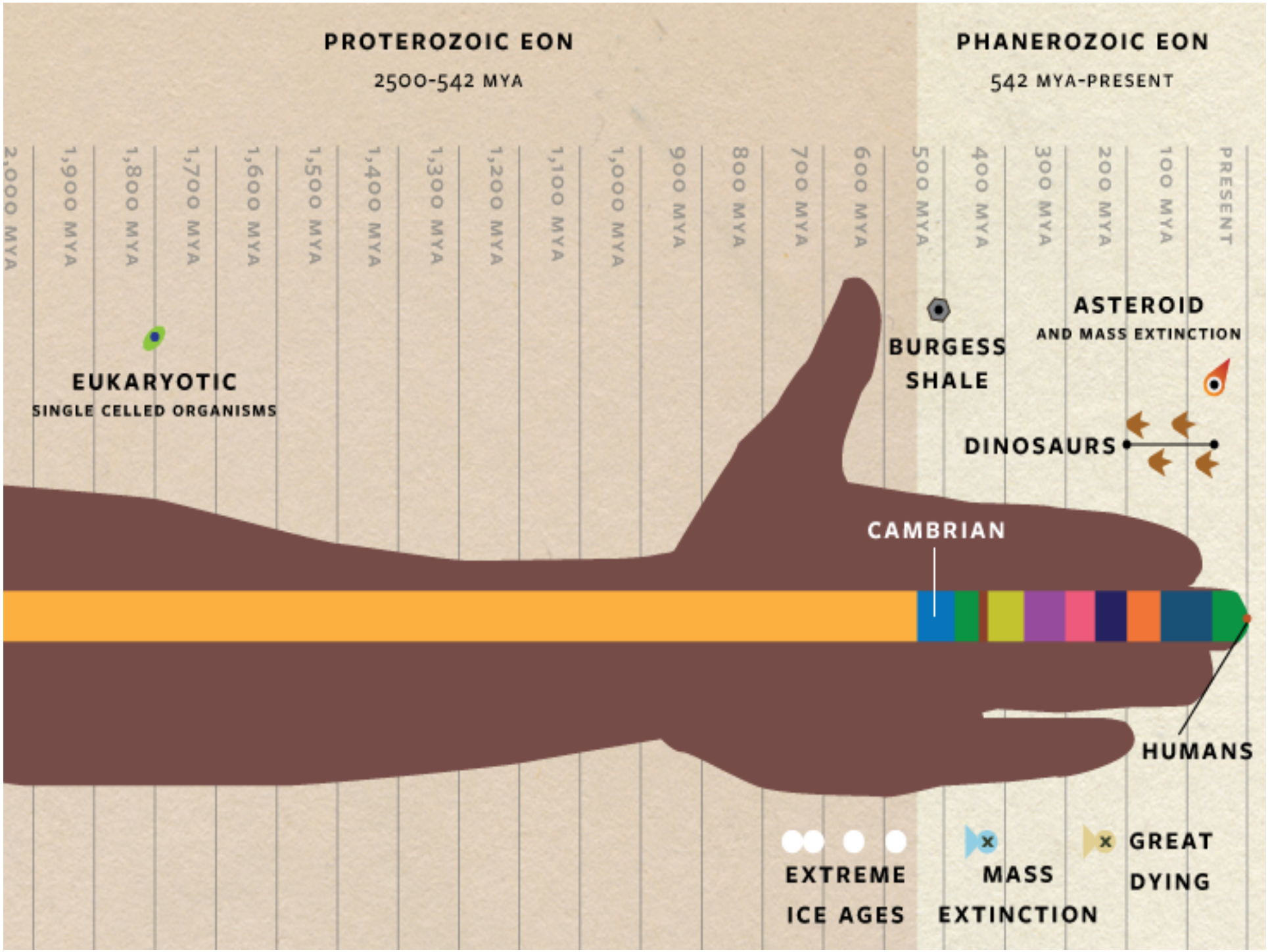
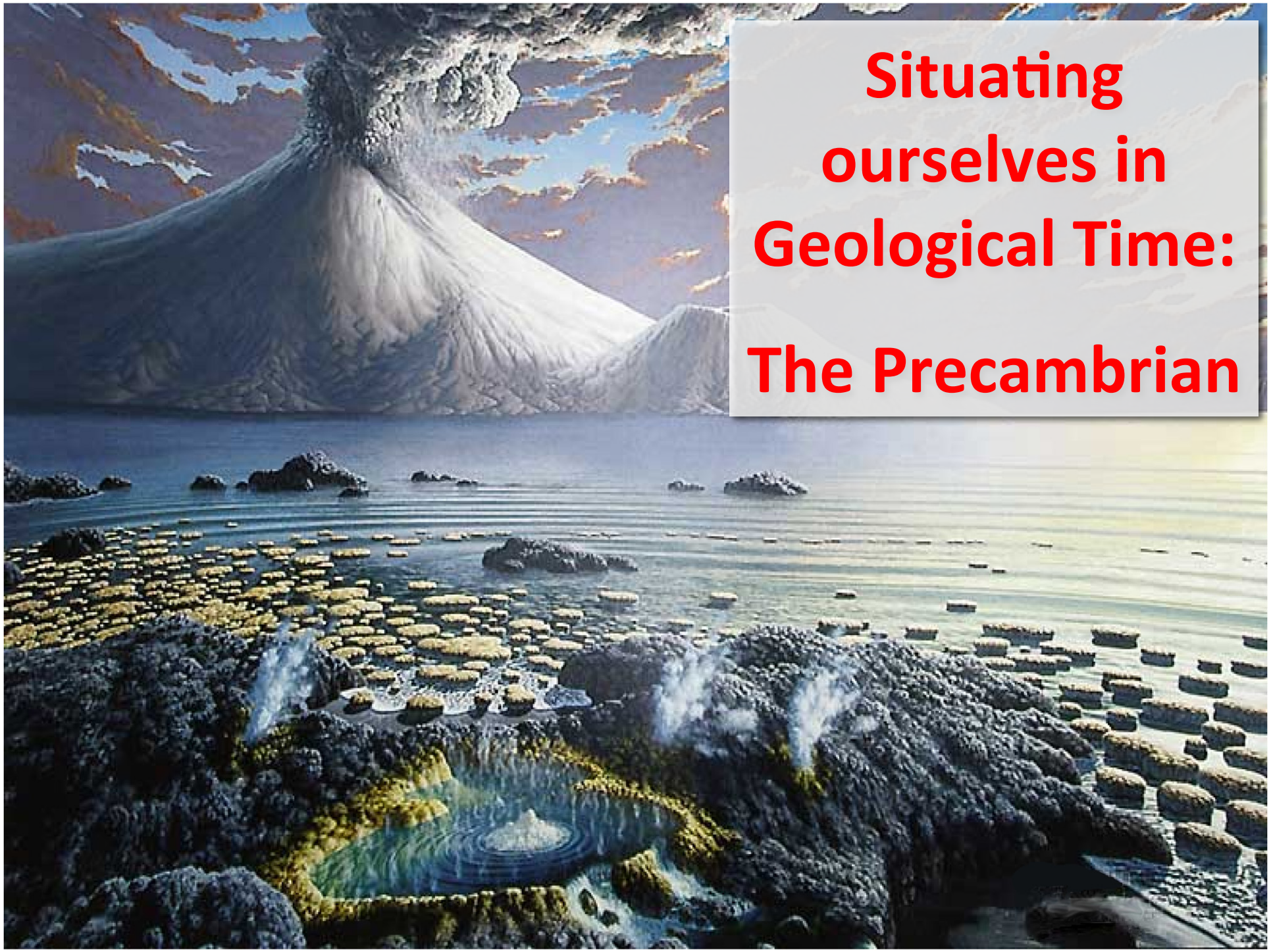

MESOZOIC ERA
200 M.Y. AGO
251 MILLION YEARS AGO
TRIASSIC PERIOD
JURASSIC PERIOD
CRETACEOUS PERIOD
65 MILLION YEARS AGO
PALEOZOIC ERA
542 M.Y. AGO
CAMBRIAN PERIOD
ORDOVICIAN PERIOD
SILURIAN PERIOD
416 M.Y. AGO
359 M.Y. AGO
PERMIAN PERIOD
PENNSYLVANIAN PERIOD
MISSISSIPPIAN PERIOD
DEVONIAN PERIOD
PRECAMBRIAN
1 BILLION YEARS AGO
2 BILLION YEARS AGO
3 BILLION YEARS AGO
EARLIEST ORGANIC STRUCTURES
4.5 BILLION YEARS AGO
CENOZOIC ERA
TERTIARY PERIOD
Paleocene Epoch
56 M.Y. AGO
Eocene Epoch
34 M.Y. AGO
Oligocene Epoch
23 M.Y. AGO
Miocene Epoch
5 M.Y. AGO
Pliocene Epoch
2 M.Y. AGO
QUATERNARY PERIOD
Pleistocene Epoch
11,500 YR. AGO
Holocene Epoch


CENOZOIC
MESOZOIC
PALEOZOIC
HOLOCENE
10,000 YEARS
PLEISTOCENE
1.8
PLIOCENE
5.3
MIOCENE
23
OLIGOCENE
33.9
EOCENE
55.8
PALEOCENE
65.5
CRETACEOUS
145.5
JURASSIC
199.6
TRIASSIC
252.2
PERMIAN
299
PENNSYLVANIAN
318
MISSISSIPPIAN
359.2
DEVONIAN
416
SILURIAN
443
ORDOVICIAN
488.3
CAMBRIAN
542
PROTEROZOIC
2.5 BILLION
ARCHEAN
EARTH FORMS 4.6 BILLION YEARS AGO
MILLIONS OF YEARS AGO
T
K
BIG, BIG EXTINCTION
T
P
GIGANTIC EXTINCTION



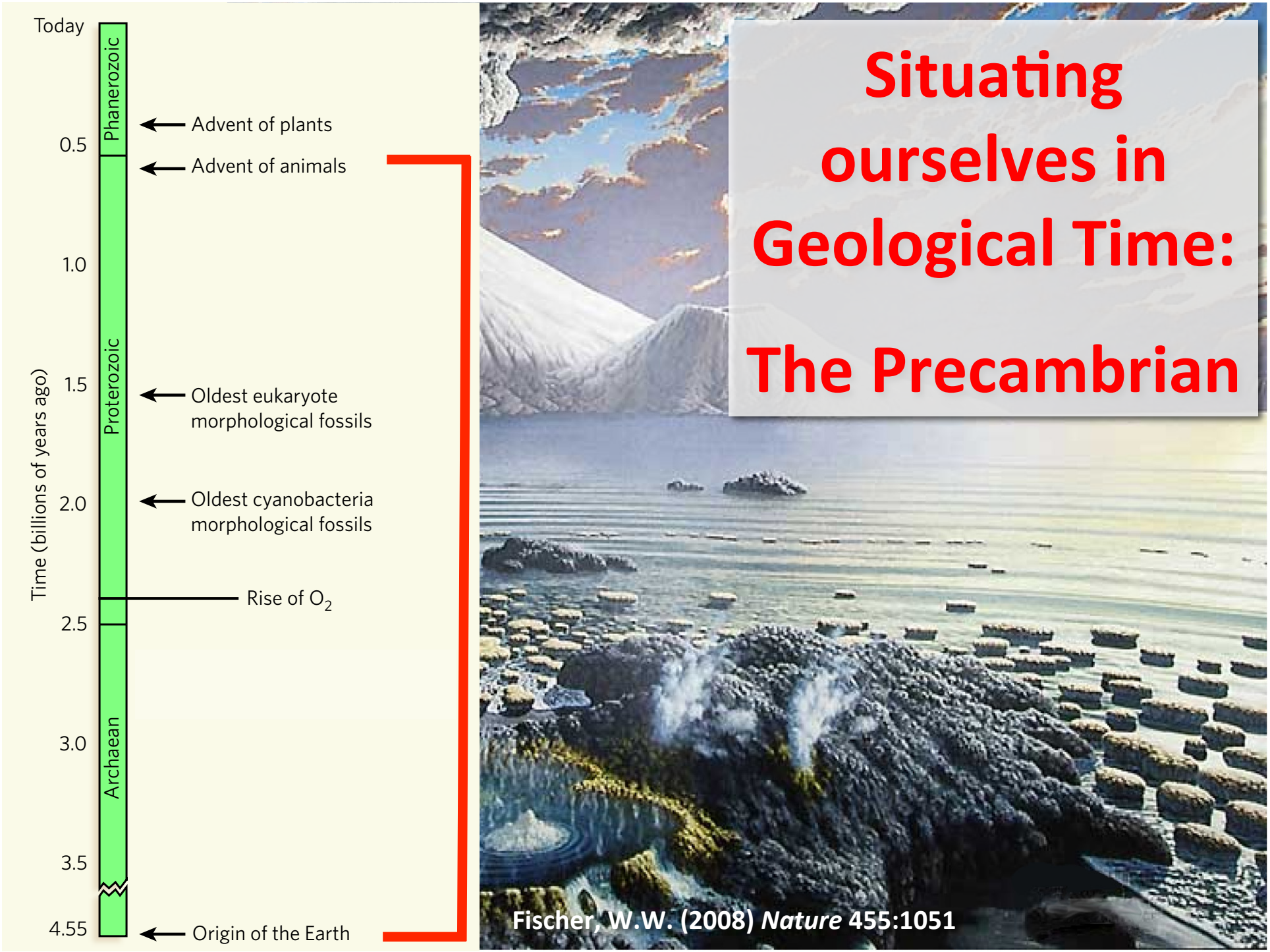
"The GSA Geologic Time Scale, not actually to scale"
http://www.geosociety.org/science/timescale/timescl.pdf.


PROTEROZOIC EON
2500-542 MYA
PHANEROZOIC EON
542 MYA-PRESENT
2,000 MYA
1,900 MYA
1,800 MYA
1,700 MYA
1,600 MYA
1,500 MYA
1,400 MYA
1,300 MYA
1,200 MYA
1,100 MYA
1,000 MYA
900 MYA
800 MYA
700 MYA
600 MYA
500 MYA
400 MYA
300 MYA
200 MYA
100 MYA
PRESENT
EUKARYOTIC
SINGLE CELLED ORGANISMS
BURGESS SHALE
ASTEROID
AND MASS EXTINCTION
DINOSAURS
CAMBRIAN
HUMANS
EXTREME ICE AGES
MASS EXTINCTION
GREAT DYING



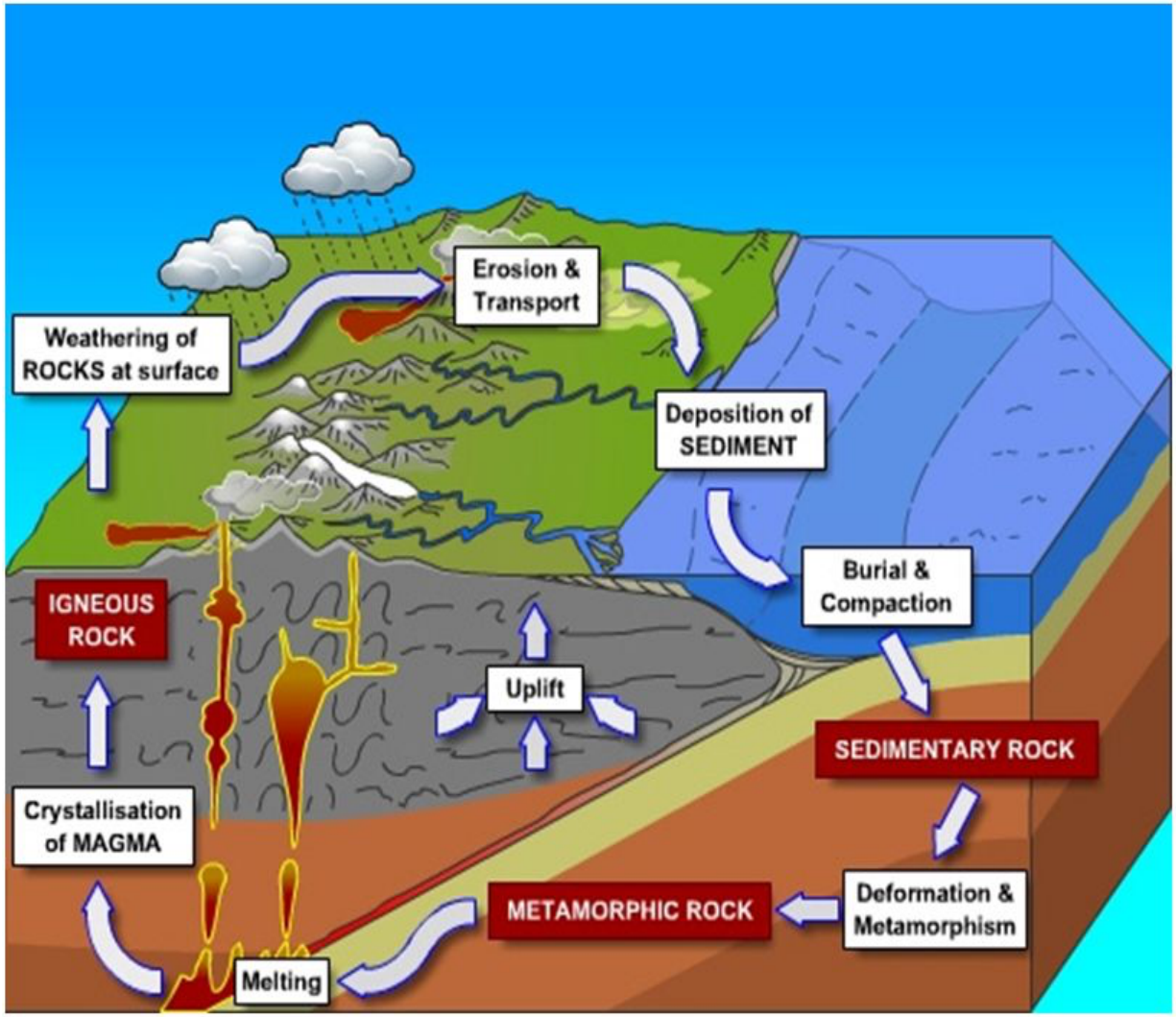
Situating ourselves in Geological Time:

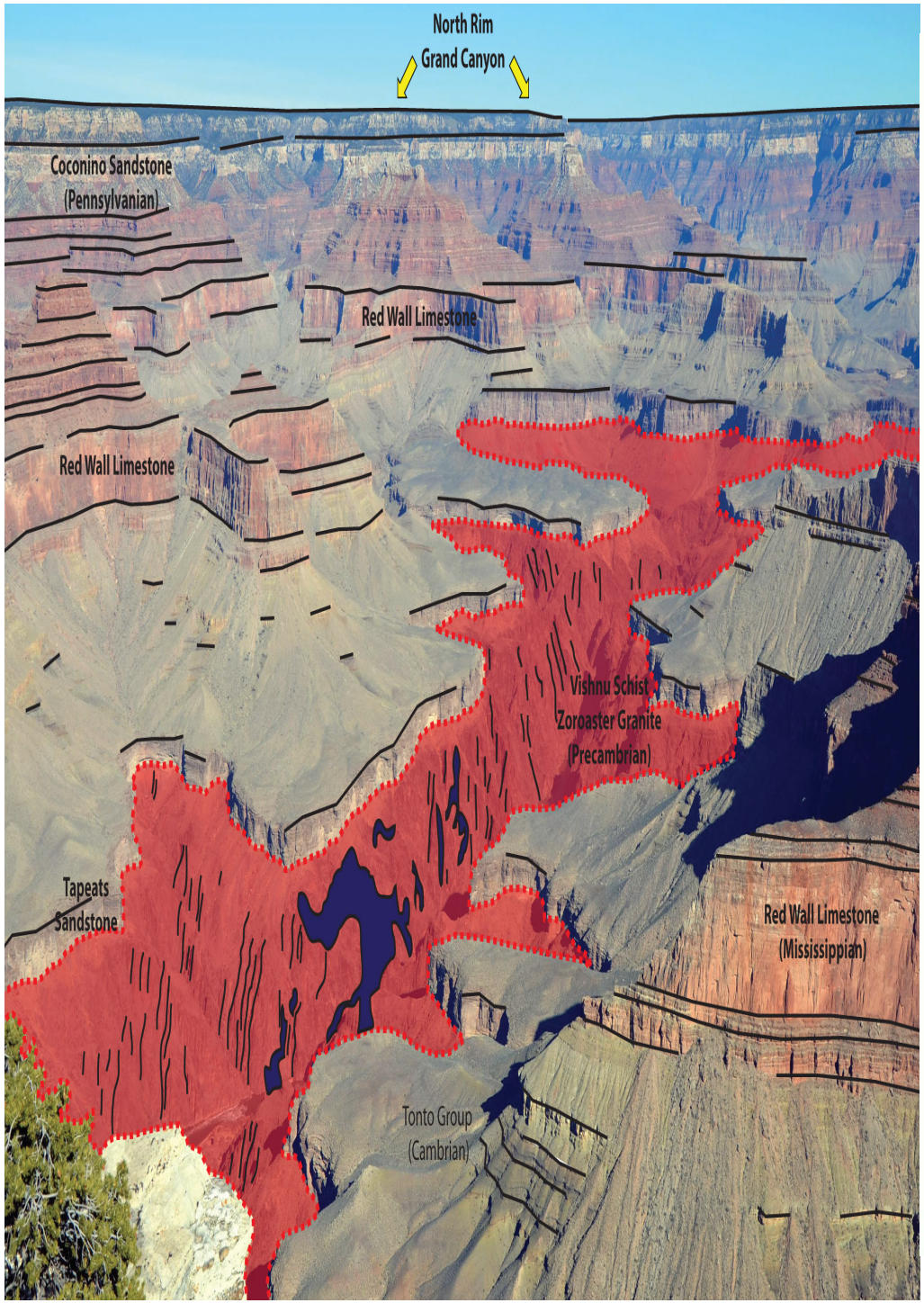
The Precambrian

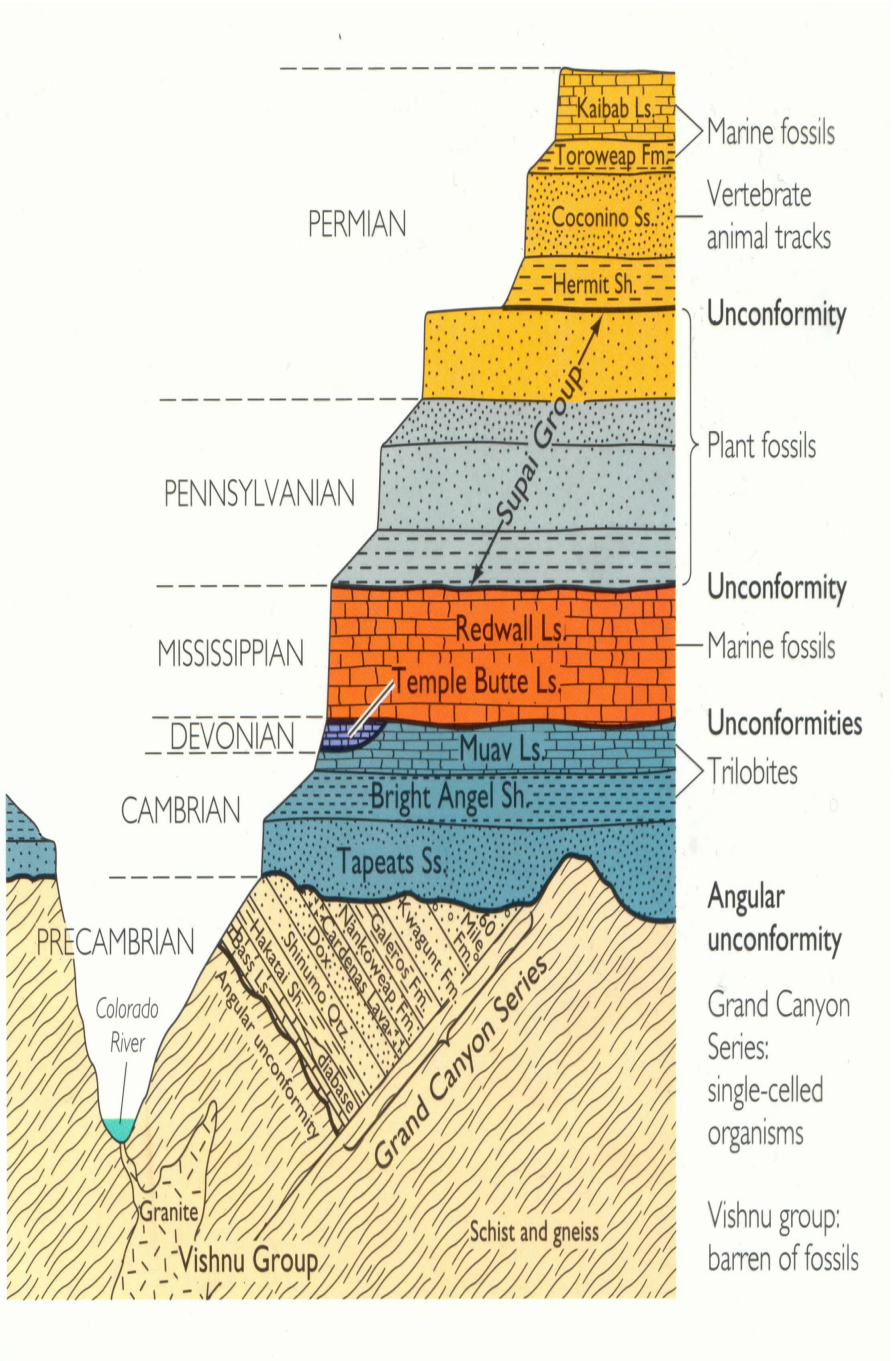

Today
Phanerozoic
Proterozoic
Archaean
Time (billions of years ago)
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.55
Advent of plants
Advent of animals
Oldest eukaryote morphological fossils
Oldest cyanobacteria morphological fossils
Rise of O_2
Origin of the Earth
Situating ourselves in Geological Time:
The Precambrian
Fischer, W.W. (2008) *Nature* 455:1051

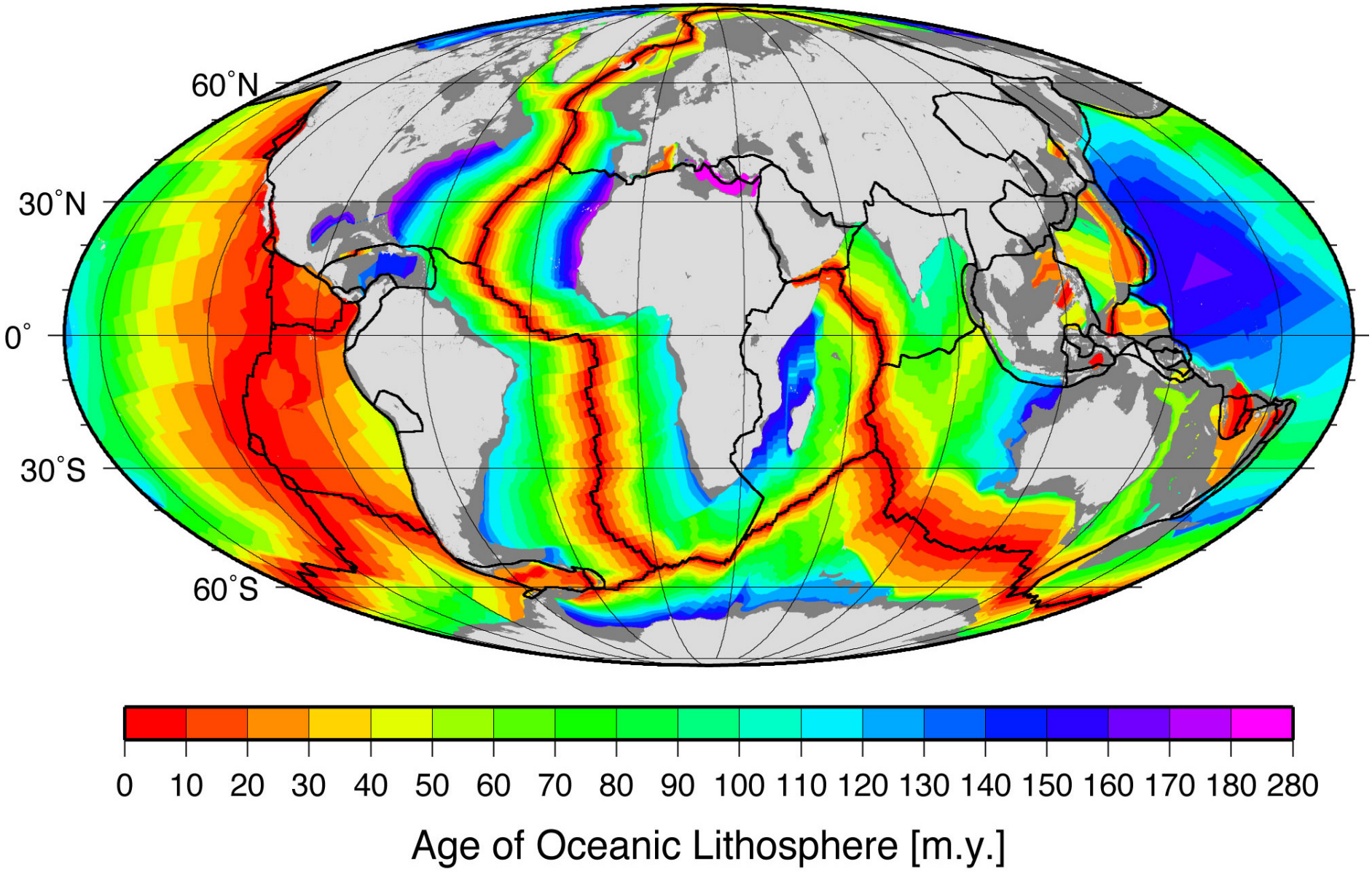
Rock Cycle

- 3 types of rock:
  - Igneous
    - volcanic rock
  - Sedimentary
    - compacted rock
  - Metamorphic
    - deformed, changing rock

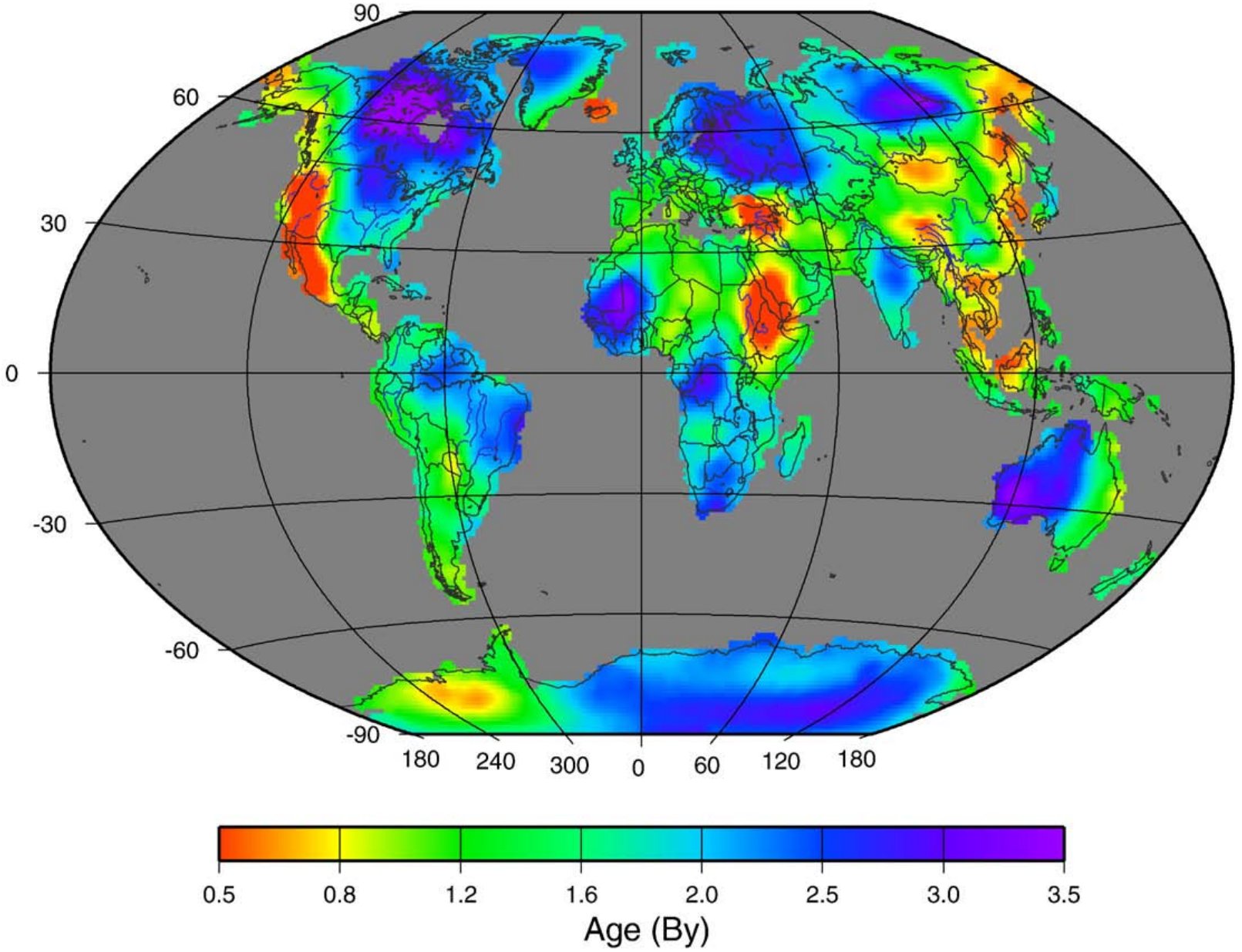



North Rim
Grand Canyon
Coconino Sandstone
(Pennsylvanian)
Red Wall Limestone
Red Wall Limestone
Vishnu Schist
Zoroaster Granite
(Precambrian)
Tapeats
Sandstone
Red Wall Limestone
(Mississippian)
Tonto Group
(Cambrian)


PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
CAMBRIAN
PRECAMBRIAN
Kaibab Ls.
Toroweap Fm.
Coconino Ss.
Hermit Sh.
Supai Group
Redwall Ls.
Temple Butte Ls.
Muav Ls.
Bright Angel Sh.
Tapeats Ss.
Colorado River
Granite
Vishnu Group
Schist and gneiss
Grand Canyon Series
Marine fossils
Vertebrate animal tracks
Unconformity
Plant fossils
Unconformity
Marine fossils
Unconformities
Trilobites
Angular unconformity
Grand Canyon Series: single-celled organisms
Vishnu group: barren of fossils


60˚N
30˚N
0˚
30˚S
60˚S
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 280
Age of Oceanic Lithosphere [m.y.]

Pour aller plus loin dans le passé… il faut des archives sédimentaires plus anciennes préservées sur les continents.

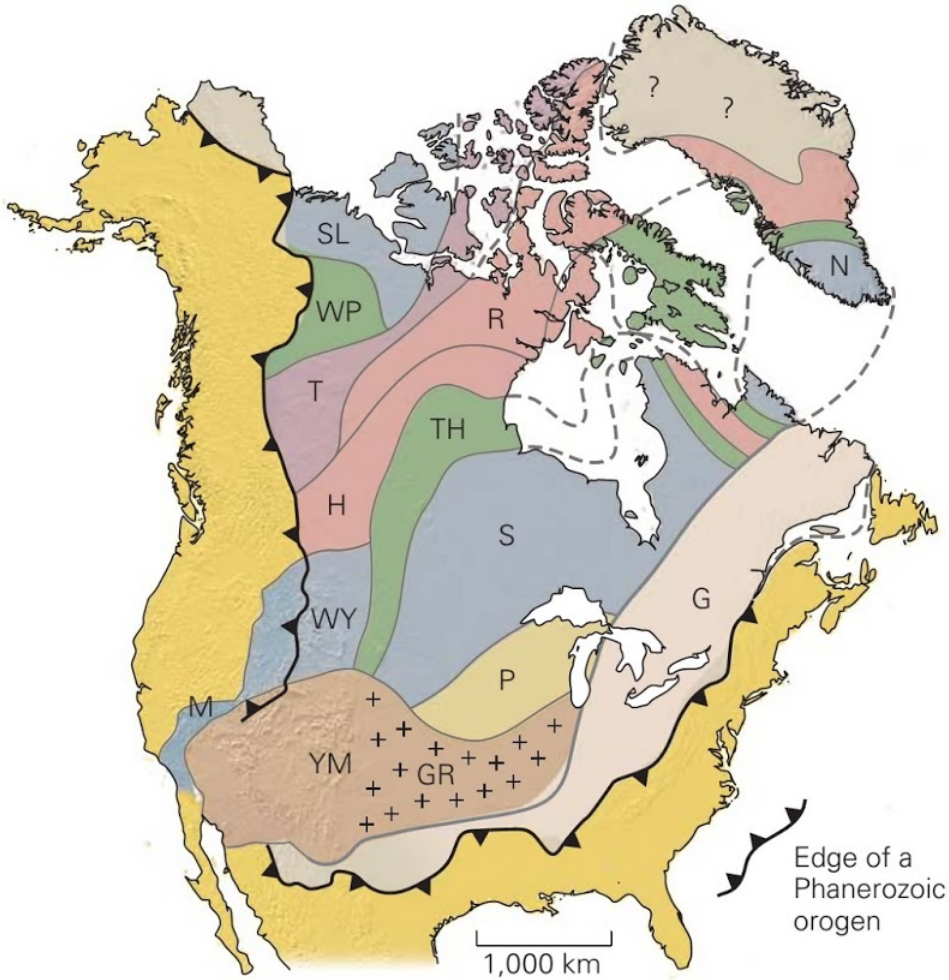


Poupinet G, Shapiro NM (2009). Lithos 109, 125-130.

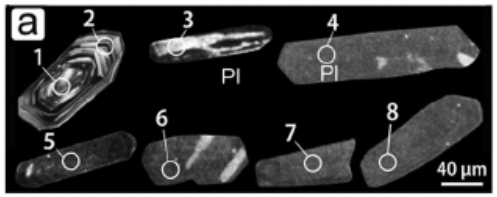
Pour aller plus loin dans le passé… il faut des archives sédimentaires plus anciennes préservées sur les continents.

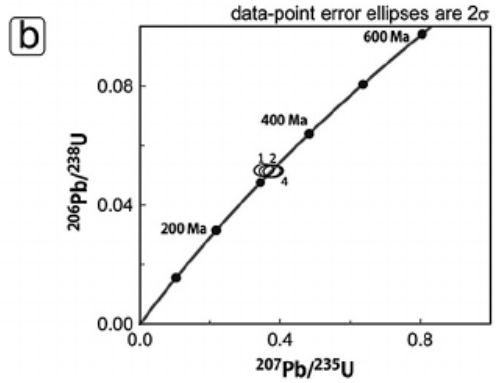
Photos: Lalonde

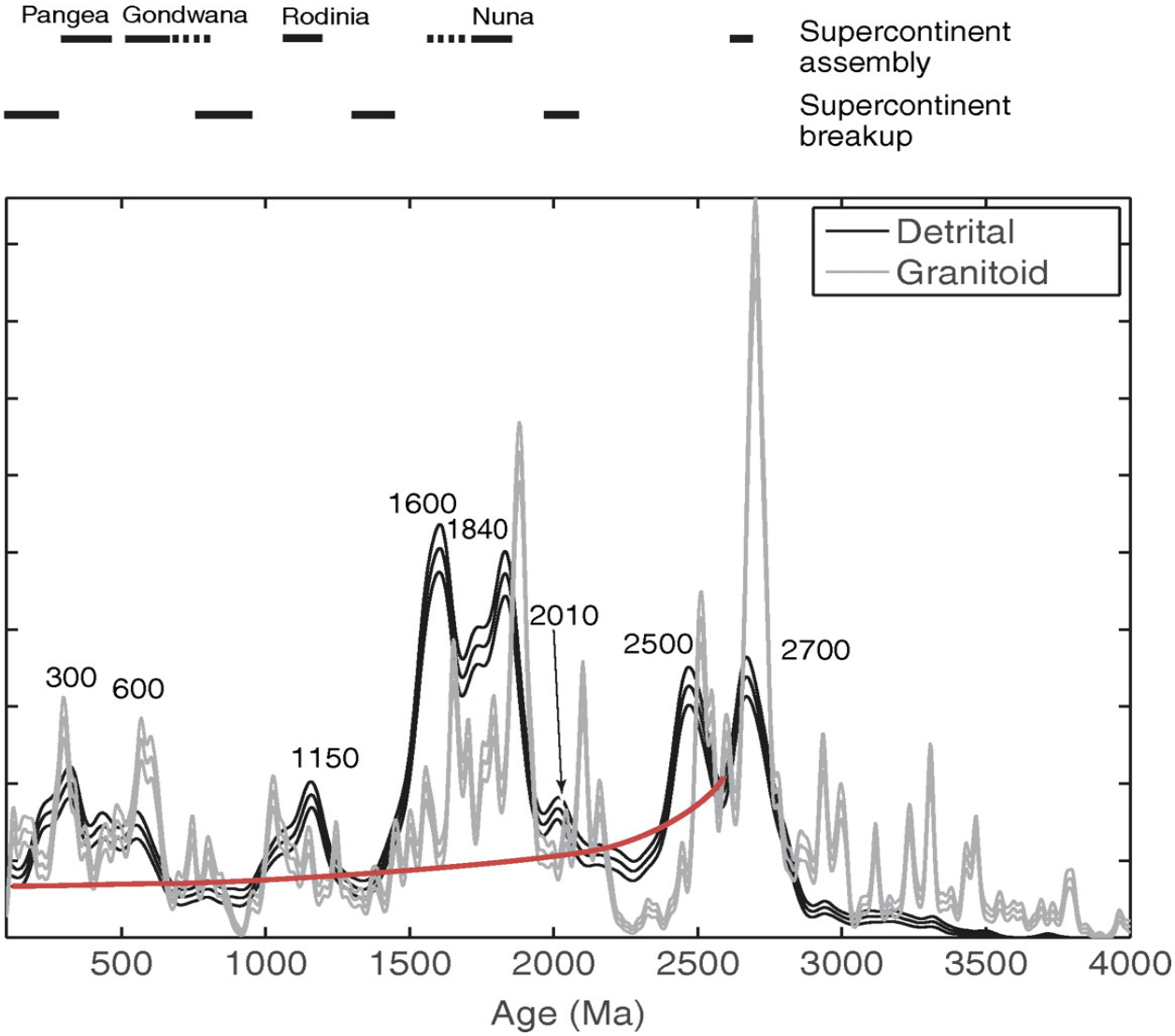
The North American craton consists of a collage of different belts and blocks stitched together during collisional and accretionary orogenies of Precambrian time.

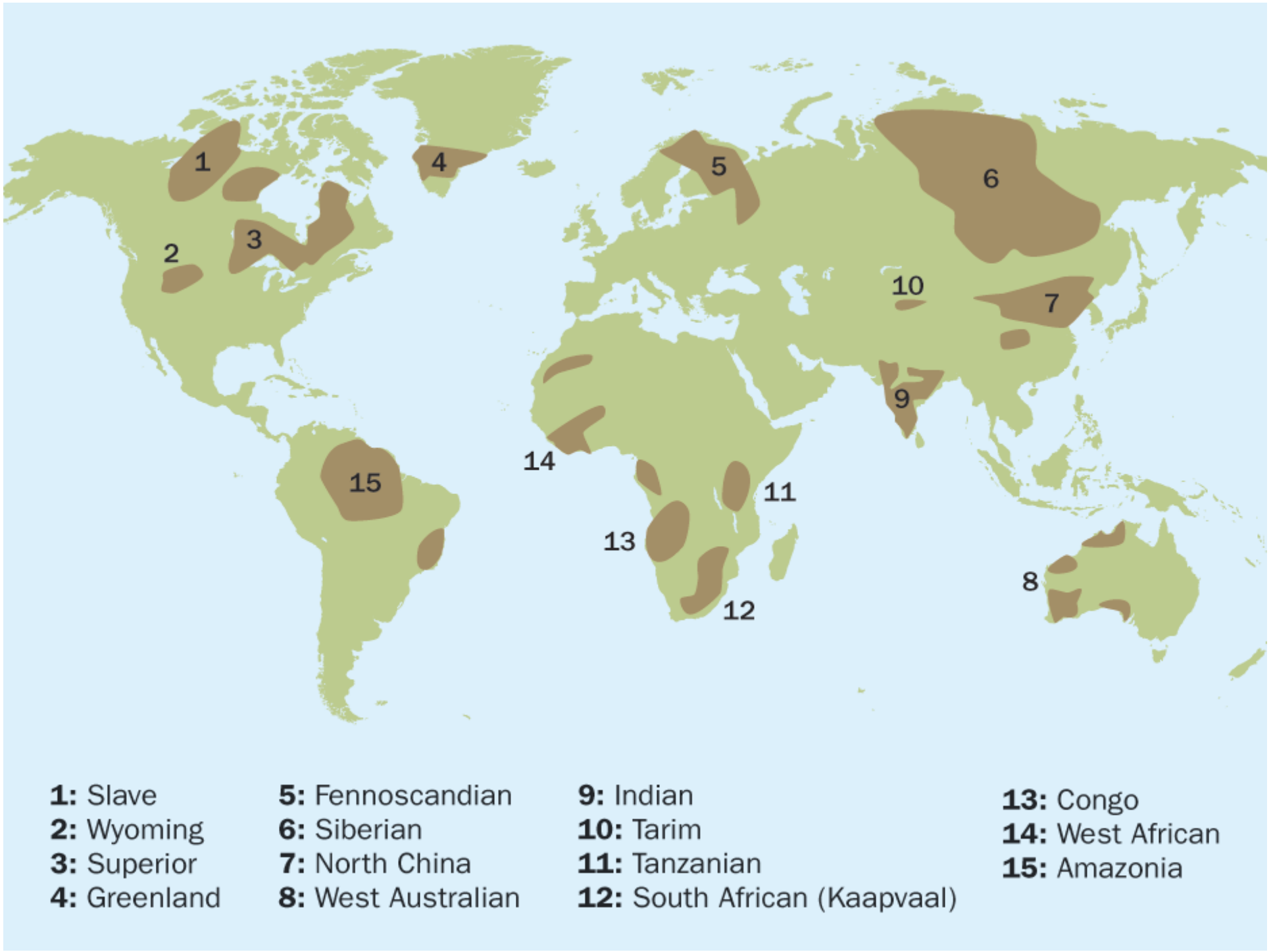


- Phanerozoic orogen
- 1.1-Ga collisional orogen (G = Grenville)
- 1.6- to 1.7-Ga accreted crust covered by granite and rhyolite, where patterned (GR = granite-rhyolite province)
- 1.6- to 1.7-Ga accreted crust (YM = Yavapai and Mazatzal)
- 1.8-Ga accreted crust (P = Penokean)
- 1.8-Ga collisional orogen (TH = Trans-Hudson; WP = Wopmay)
- 1.9-Ga collisional orogen (T = Thelon)
- Archean rocks, later deformed and metamorphosed in the Proterozoic (H = Hearn; R = Rae)
- Relicts of Archean crust (WY = Wyoming; M = Mojave; S = Superior; N = Nain; SL = Slave)

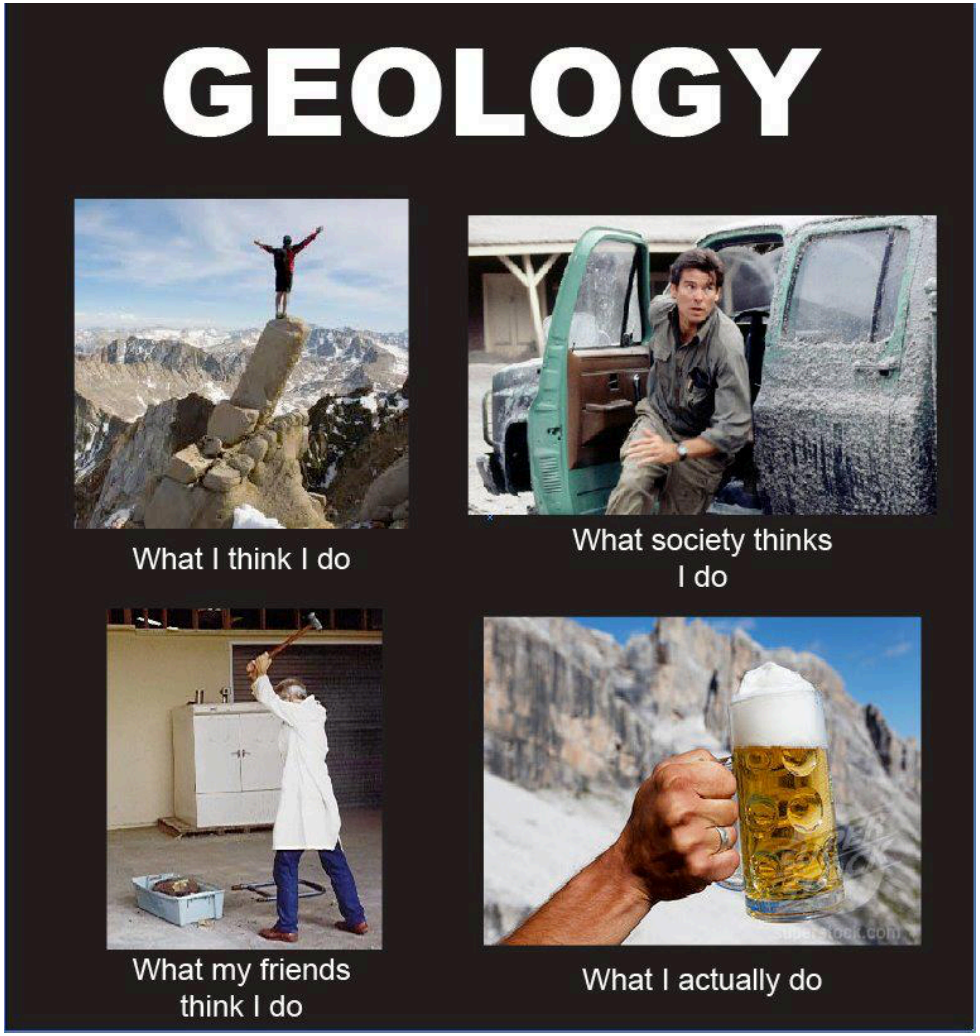

a
1
2
3
Pl
4
Pl
5
6
7
8
40 µm


b
data-point error ellipses are 2σ
600 Ma
400 Ma
200 Ma
1
2
4
0.08
0.04
0.00
0.0
0.4
0.8
206Pb/238U
207Pb/235U


Pangea
Gondwana
Rodinia
Nuna
Supercontinent assembly
Supercontinent breakup
Detrital
Granitoid
Probability density x 10^3
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
300
600
1150
1600
1840
2010
2500
2700
500
1000
1500
2000
2500
3000
3500
4000
Age (Ma)

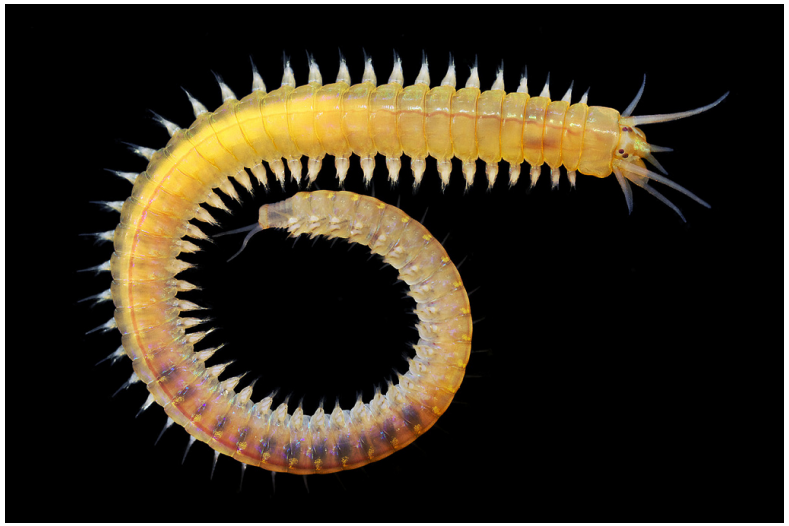

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
1: Slave
2: Wyoming
3: Superior
4: Greenland
5: Fennoscandian
6: Siberian
7: North China
8: West Australian
9: Indian
10: Tarim
11: Tanzanian
12: South African (Kaapvaal)
13: Congo
14: West African
15: Amazonia

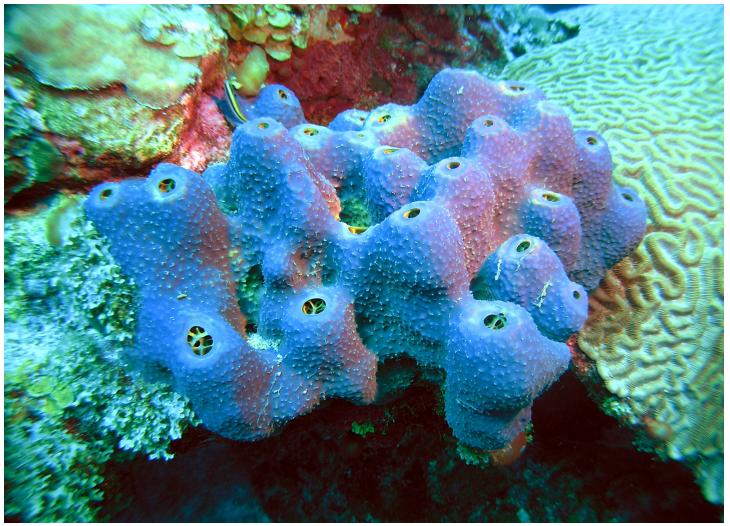
Pour l’instant nous sommes partis sur l’archive géologique…

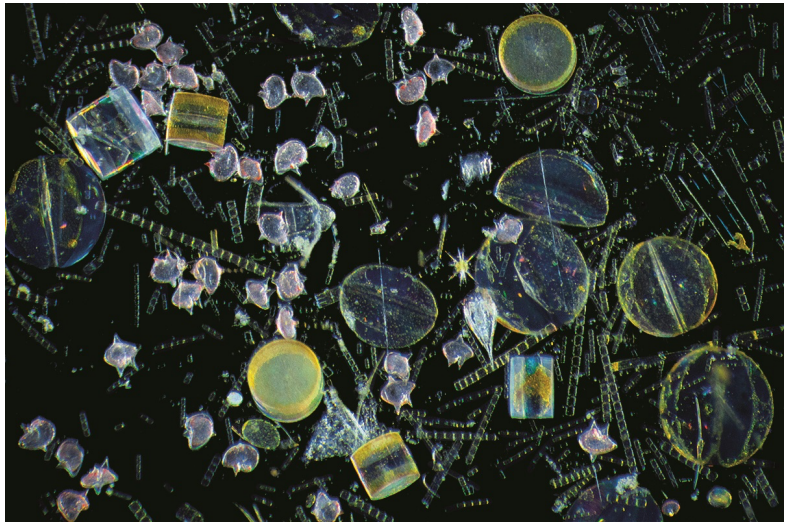


Même pas besoin de se déplacer pour trouver des traces de la vie primitive…

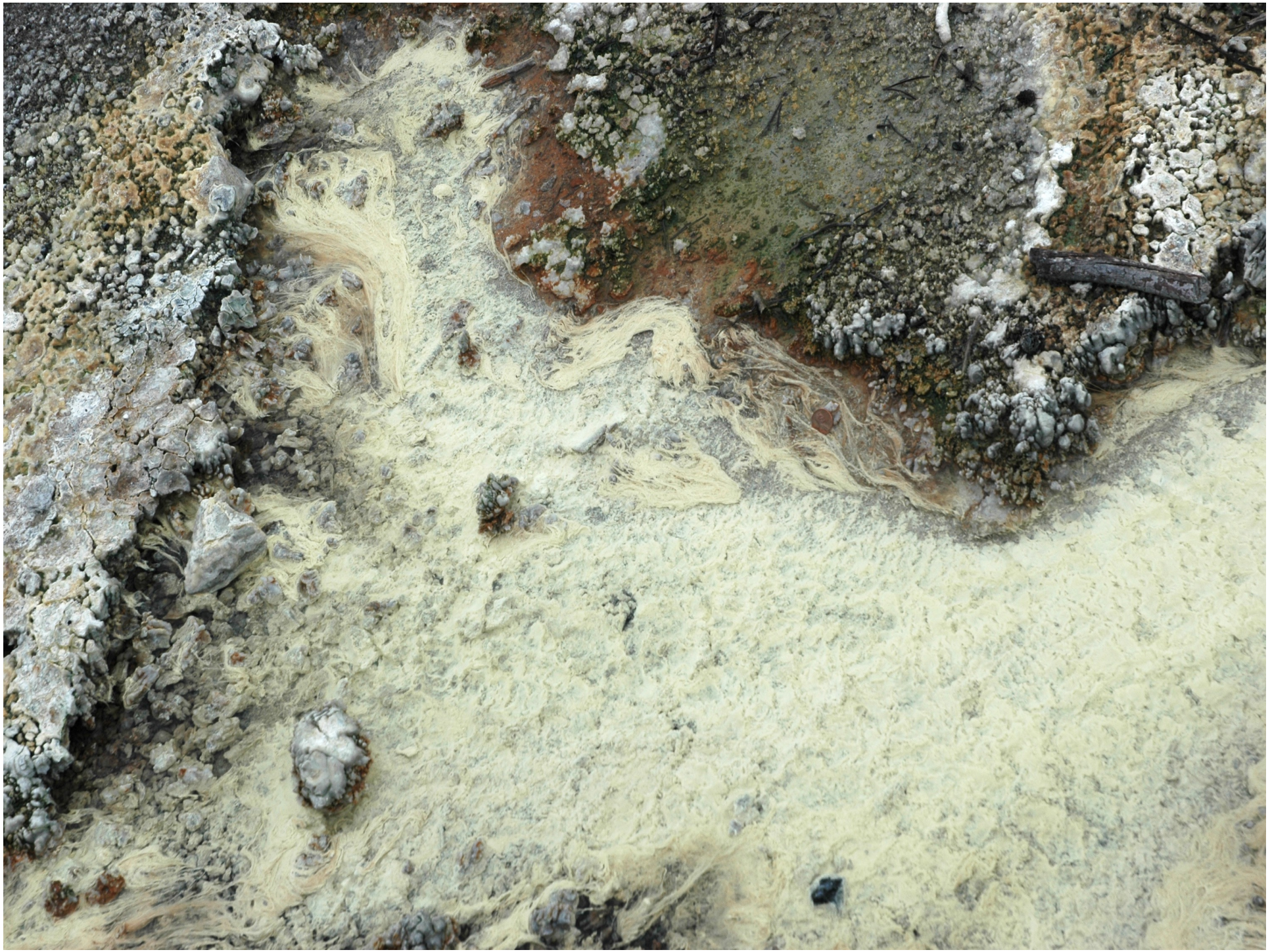
On est entouré!

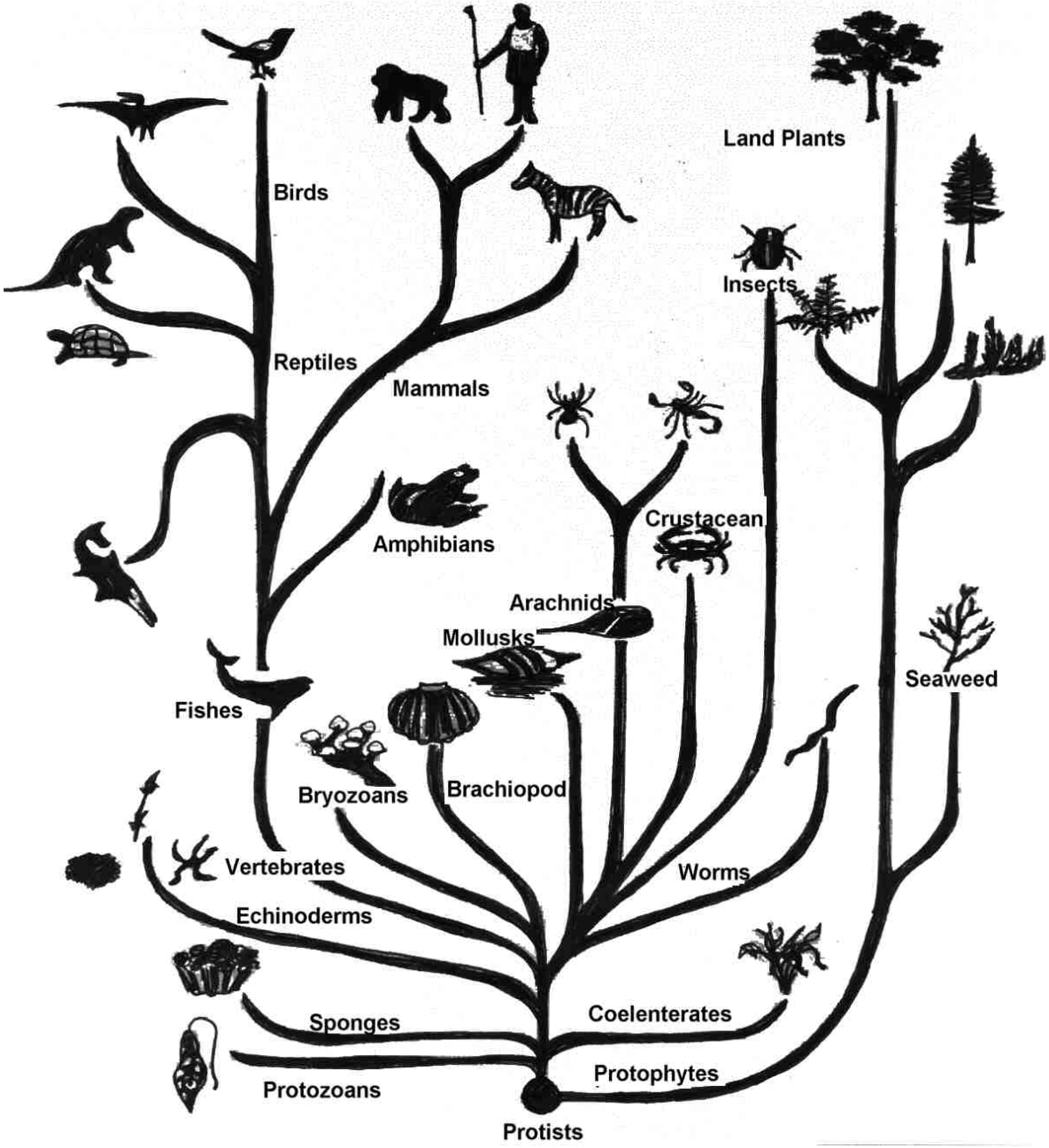


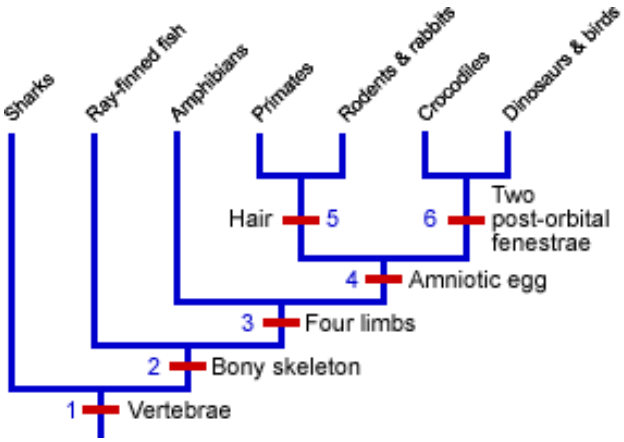


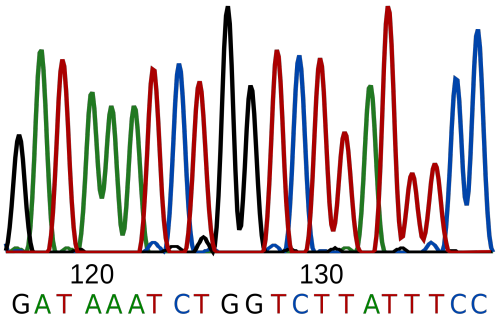


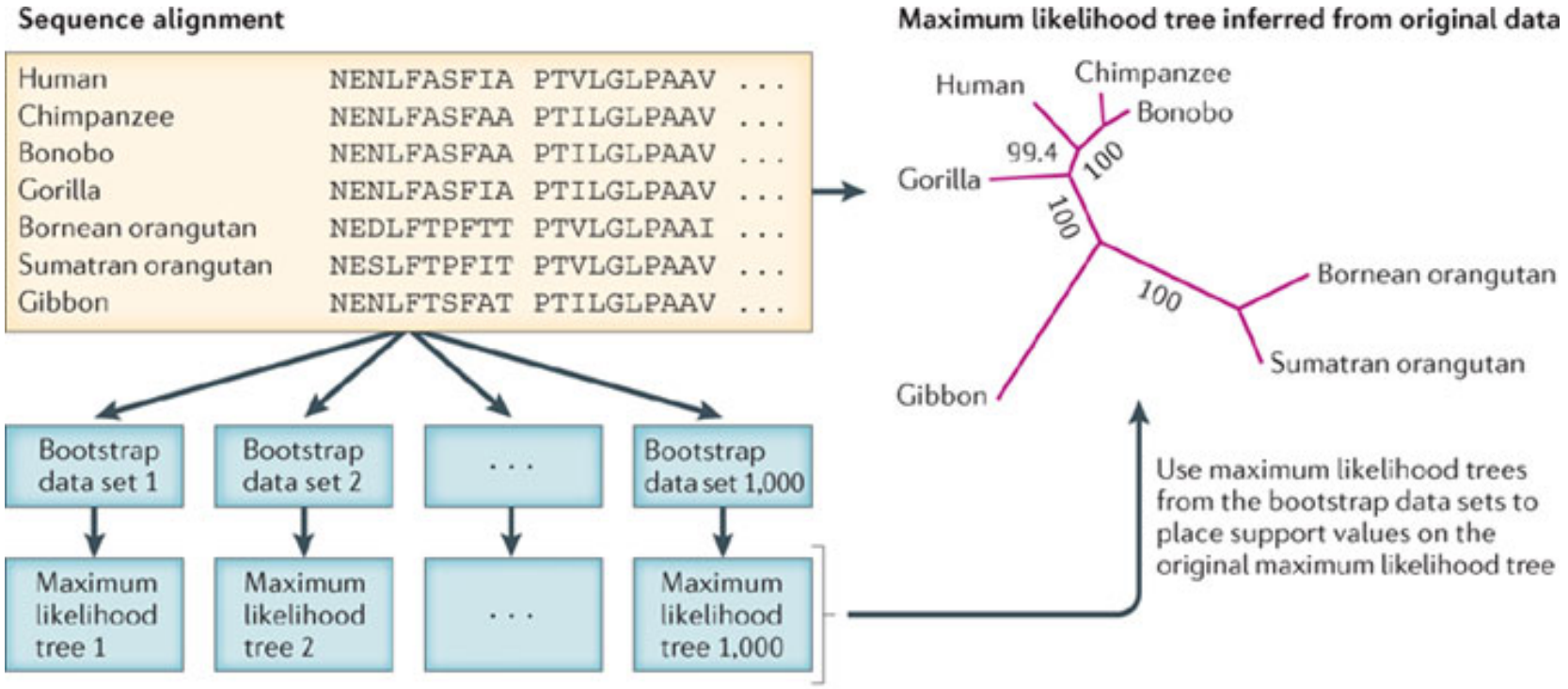
MT
ID
WY
Yellowstone
Alaska is
1/2 scale



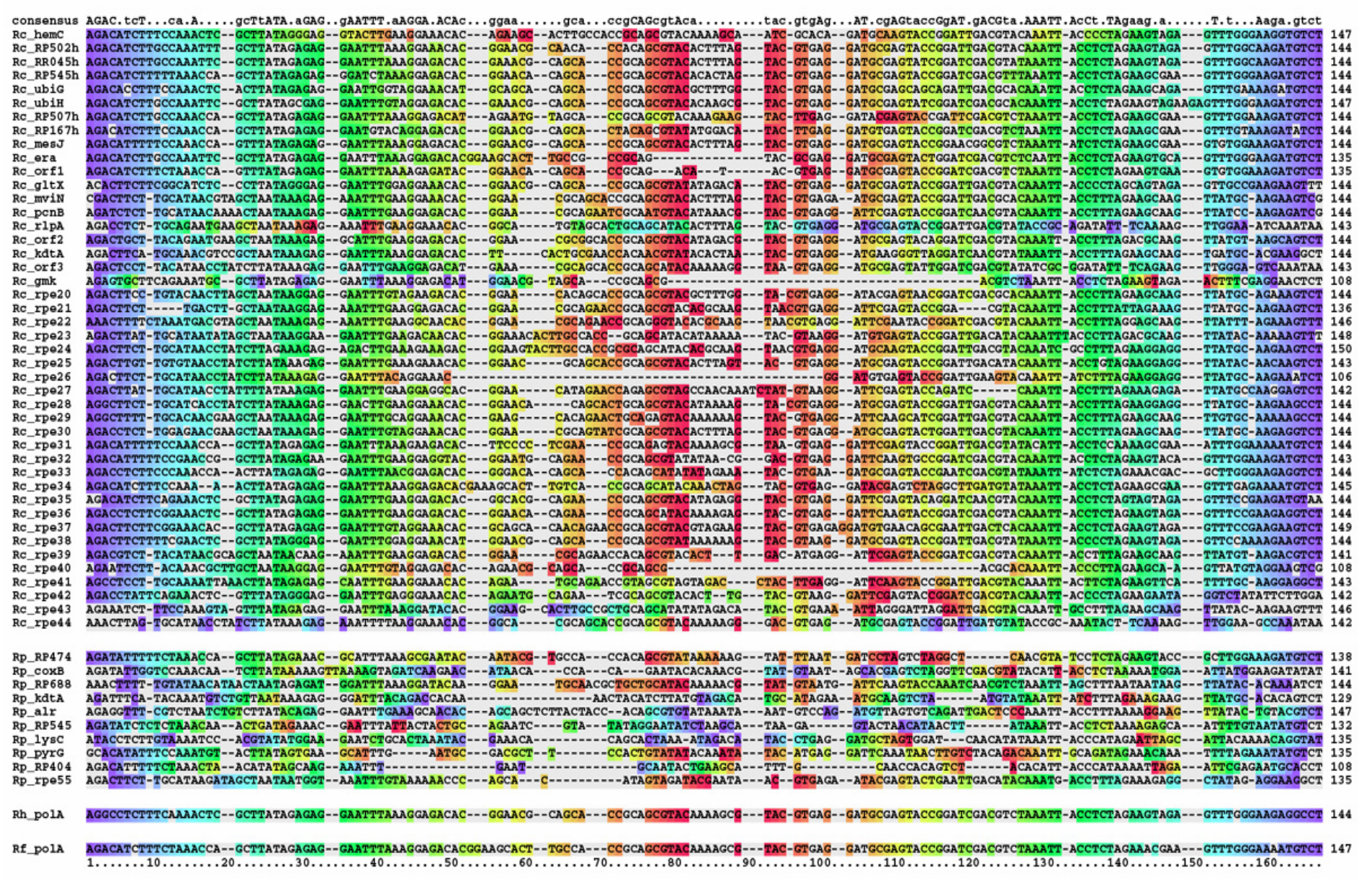

Land Plants
Birds
Insects
Reptiles
Mammals
Amphibians
Crustacean
Arachnids
Mollusks
Seaweed
Fishes
Bryozoans
Brachiopod
Vertebrates
Worms
Echinoderms
Sponges
Coelenterates
Protophytes
Protozoans
Protists

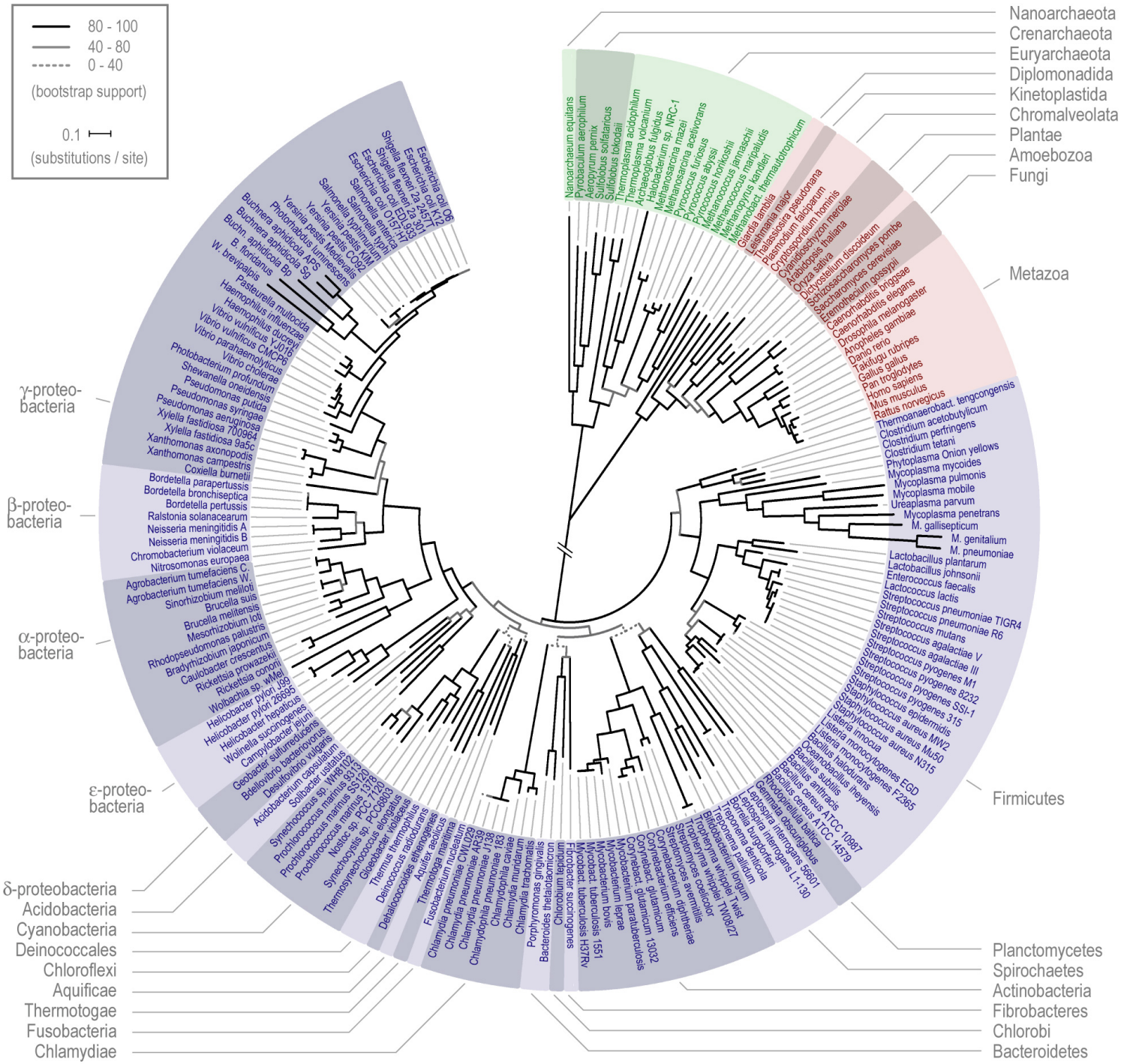

Sharks
Ray-finned fish
Amphibians
Primates
Rodents & rabbits
Crocodiles
Dinosaurs & birds
Hair
5
6
Two post-orbital fenestrae
4
Amniotic egg
3
Four limbs
2
Bony skeleton
1
Vertebrae

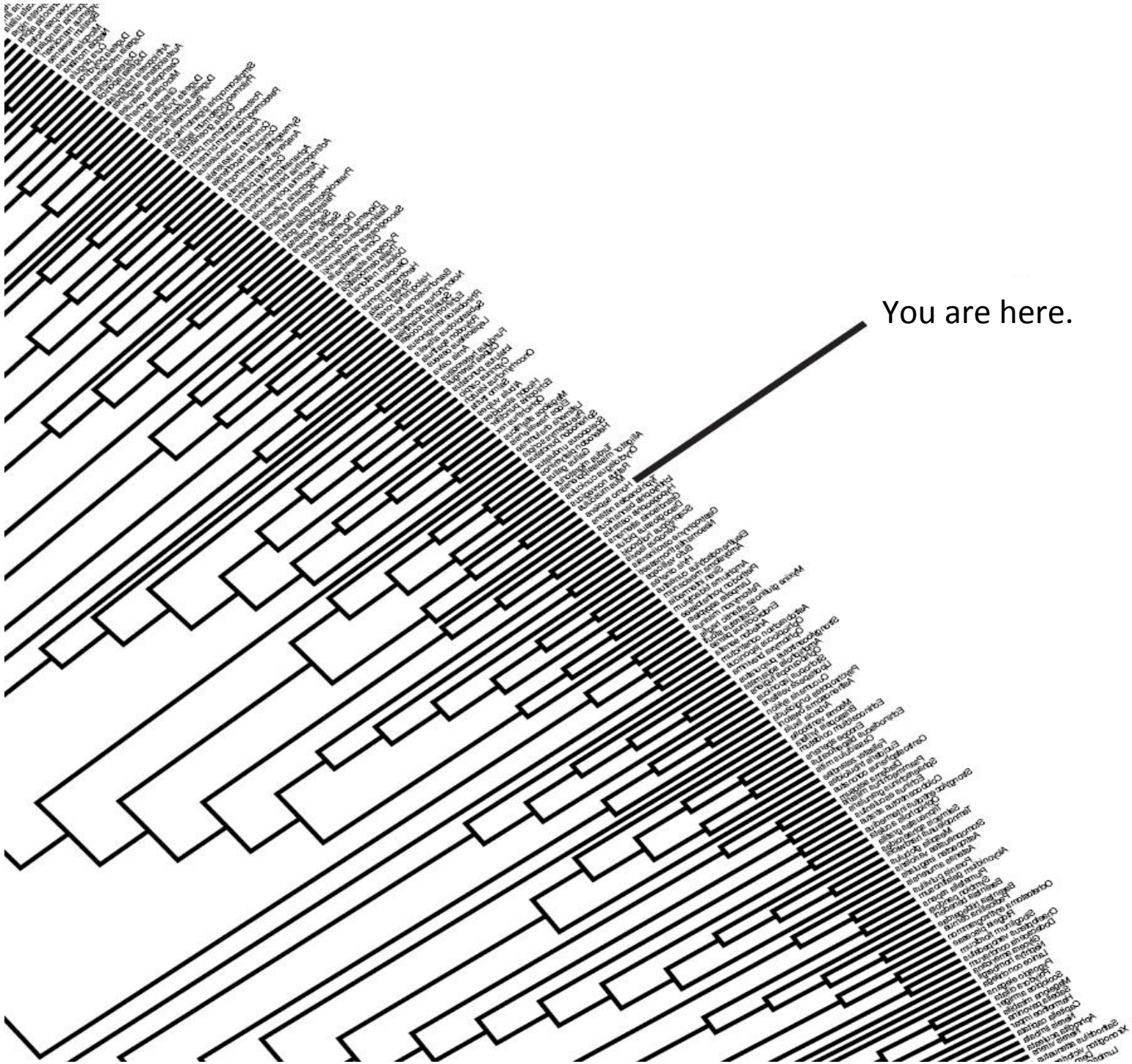




Nature Reviews | Genetics




80 - 100
40 - 80
0 - 40
(bootstrap support)
0.1
(substitutions / site)
Nanoarchaeota
Crenarchaeota
Euryarchaeota
Diplomonadida
Kinetoplastida
Chromalveolata
Plantae
Amoebozoa
Fungi
Metazoa
Firmicutes
Planctomycetes
Spirochaetes
Actinobacteria
Fibrobacteres
Chlorobi
Bacteroidetes
Chlamydiae
Fusobacteria
Thermotogae
Aquificae
Deinococcales
Cyanobacteria
Acidobacteria
δ-proteobacteria
ε-proteo-bacteria
α-proteo-bacteria
β-proteo-bacteria
γ-proteo-bacteria
Nanoarchaeum equitans
Pyrobaculum aerophilum
Aeropyrum pernix
Sulfolobus solfataricus
Sulfolobus tokodaii
Thermoplasma acidophilum
Thermoplasma volcanium
Archeoglobus fulgidus
Halobacterium sp. NRC-1
Methanosarcina mazei
Pyrococcus furiosus
Pyrococcus abyssi
Pyrococcus horikoshii
Methanococcus jannaschii
Methanopyrus kandleri
Methanobact. thermautotrophicum
Giardia lamblia
Leishmania major
Thalassiosira pseudonana
Plasmodium falciparum
Cryptosporidium hominis
Cyanidioschyzon merolae
Arabidopsis thaliana
Oryza sativa
Dictyostelium discoideum
Schizosaccharomyces pombe
Saccharomyces cerevisiae
Saccharomyces gossypii
Tremelhedium bingsae
Caenorhabditis elegans
Caenorhabditis briggsae
Drosophila melanogaster
Anopheles gambiae
Danio rerio
Takifugu rubripes
Gallus gallus
Pan troglodytes
Homo sapiens
Mus musculus
Rattus norvegicus
Thermoanaerobact. tengcongensis
Clostridium acetobutylicum
Clostridium perfringens
Clostridium tetani
Phytoplasma Onion yellows
Mycoplasma mycoides
Mycoplasma pulmonis
Mycoplasma mobile
Ureaplasma parvum
Mycoplasma penetrans
M. gallisepticum
M. genitalium
M. pneumoniae
Lactobacillus plantarum
Lactobacillus johnsonii
Enterococcus faecalis
Lactococcus lactis
Streptococcus pneumoniae TIGR4
Streptococcus pneumoniae R6
Streptococcus mutans
Streptococcus agalactiae V
Streptococcus agalactiae III
Streptococcus pyogenes M1
Streptococcus pyogenes 8232
Streptococcus pyogenes SSI-1
Streptococcus pyogenes 315
Staphylococcus epidermidis
Staphylococcus aureus MW2
Staphylococcus aureus Mu50
Staphylococcus aureus N315
Listeria innocua
Listeria monocytogenes EGD
Listeria monocytogenes F2365
Bacillus halodurans
Bacillus subtilis
Oceanobacillus iheyensis
Bacillus anthracis
Bacillus cereus ATCC 10987
Bacillus cereus ATCC 14579
Rhodopirellula baltica
Gemmata obscuriglobus
Leptospira interrogans 56601
Leptospira interrogans L1-130
Borrelia burgdorferi
Treponema pallidum
Treponema denticola
Bifidobacterium longum
Tropheryma whipplei Twist
Tropheryma whipplei TW08/27
Streptomyces coelicolor
Streptomyces avermitilis
Corynebacterium diphtheriae
Corynebacterium efficiens
Corynebact. glutamicum
Corynebact. glutamicum 13032
Corynebacterium paratuberculosis
Mycobacterium leprae
Mycobacterium bovis
Mycobact. tuberculosis 1551
Mycobact. tuberculosis H37Rv
Fibrobacter succinogenes
Chlorobium tepidum
Porphyromonas gingivalis
Bacteroides thetaiotaomicron
Chlamydia trachomatis
Chlamydia muridarum
Chlamydophila caviae
Chlamydia pneumoniae 1138
Chlamydia pneumoniae AR39
Chlamydia pneumoniae CWL029
Chlamydia pneumoniae J138
Fusobacterium nucleatum
Thermotoga maritima
Aquifex aeolicus
Deinococcus radiodurans
Thermus thermophilus
Deinococcus geothermalis
Dehalococcoides ethenogenes
Gloeobacter violaceus
Thermosynechococcus elongatus
Nostoc sp. PCC7120
Synechocystis sp. PCC6803
Prochlorococcus marinus SS120
Prochlorococcus marinus MED4
Prochlorococcus marinus MIT9313
Prochlorococcus sp. MED4
Synechococcus sp. WH8102
Acidobacterium capsulatum
Solibacter usitatus
Geobacter sulfurreducens
Bdellovibrio bacteriovorus
Desulfovibrio vulgaris
Wolinella succinogenes
Campylobacter jejuni
Helicobacter hepaticus
Helicobacter pylori 26695
Helicobacter pylori J99
Wolbachia sp. wMel
Rickettsia conorii
Rickettsia prowazekii
Caulobacter crescentus
Bradyrhizobium japonicum
Rhodopseudomonas palustris
Mesorhizobium loti
Brucella melitensis
Brucella suis
Sinorhizobium meliloti
Agrobacterium tumefaciens W.
Agrobacterium tumefaciens C.
Nitrosomonas europaea
Chromobacterium violaceum
Neisseria meningitidis B
Neisseria meningitidis A
Ralstonia solanacearum
Bordetella pertussis
Bordetella bronchiseptica
Bordetella parapertussis
Coxiella burnetii
Xanthomonas campestris
Xanthomonas axonopodis
Xylella fastidiosa 9a5c
Xylella fastidiosa 700964
Pseudomonas aeruginosa
Pseudomonas syringae
Pseudomonas putida
Shewanella oneidensis
Photobacterium profundum
Vibrio cholerae
Vibrio parahaemolyticus
Vibrio vulnificus CMCP6
Vibrio vulnificus YJ016
Haemophilus ducreyi
Haemophilus influenzae
Pasteurella multocida
W. brevipalpis
B. floridanus
Buchn. aphidicola Sg
Buchnera aphidicola Bp
Buchnera aphidicola APS
Photorhabdus luminescens
Yersinia pestis Medievalis
Yersinia pestis KIM
Yersinia pestis CO92
Salmonella typhimurium
Salmonella enterica
Escherichia coli O157:H7
Escherichia coli EDL933
Shigella flexneri 2a 2457T
Shigella flexneri 2a 301
Escherichia coli K12
Escherichia coli O6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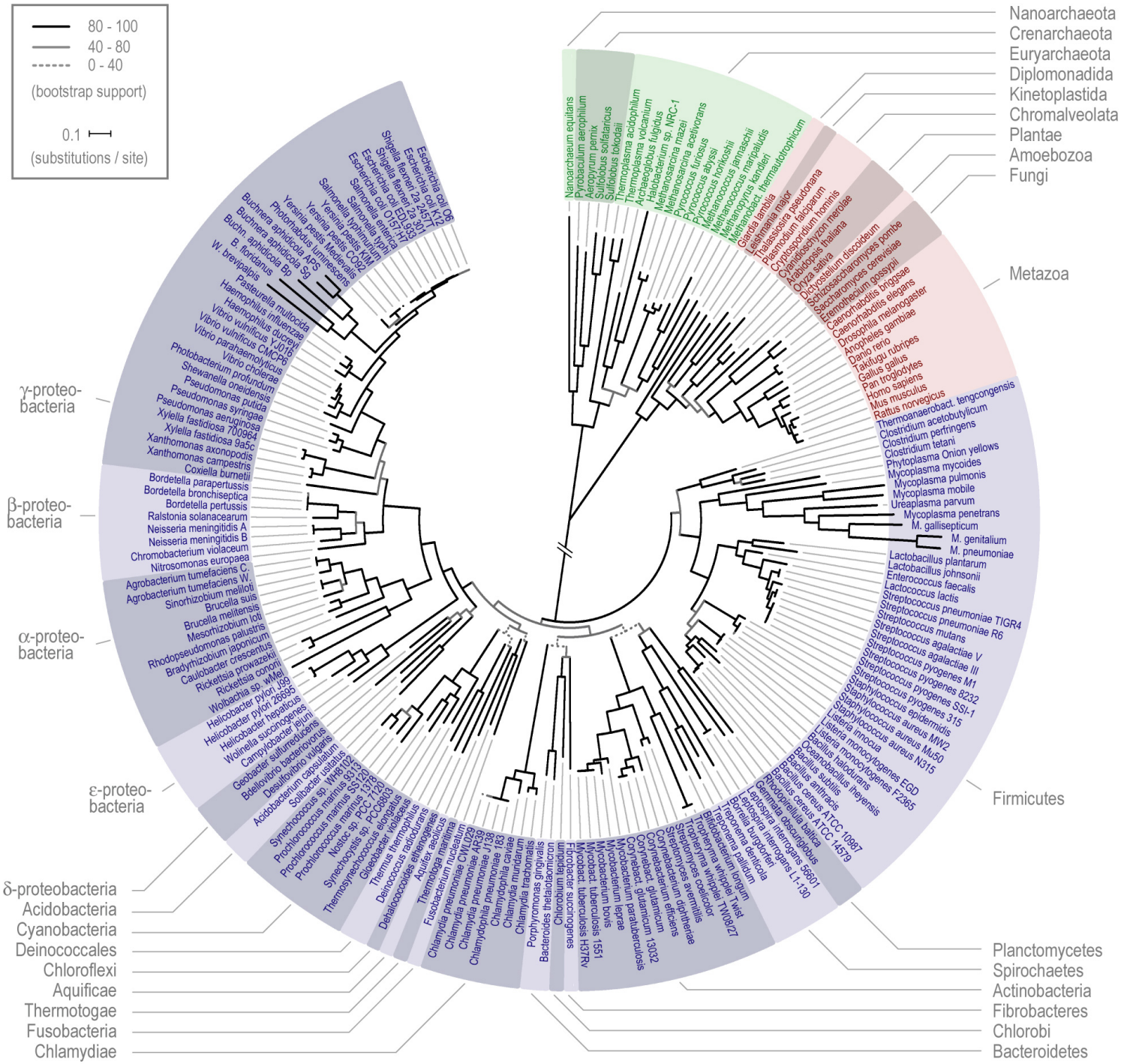
80 - 100
40 - 80
0 - 40
(bootstrap support)
0.1
(substitutions / site)
Nanoarchaeota
Crenarchaeota
Euryarchaeota
Diplomonadida
Kinetoplastida
Chromalveolata
Plantae
Amoebozoa
Fungi
Metazoa
Firmicutes
Planctomycetes
Spirochaetes
Actinobacteria
Fibrobacteres
Chlorobi
Bacteroidetes
Chlamydiae
Fusobacteria
Thermotogae
Aquificae
Deinococcales
Cyanobacteria
Acidobacteria
δ-proteobacteria
ε-proteo-bacteria
α-proteo-bacteria
β-proteo-bacteria
γ-proteo-bacteria
Nanoarchaeum equitans
Pyrobaculum aerophilum
Aeropyrum pernix
Sulfolobus solfataricus
Sulfolobus tokodaii
Thermoplasma acidophilum
Thermoplasma volcanium
Archeoglobus fulgidus
Halobacterium sp. NRC-1
Methanosarcina mazei
Pyrococcus furiosus
Pyrococcus abyssi
Pyrococcus horikoshii
Methanococcus jannaschii
Methanopyrus kandleri
Methanobact. thermautotrophicum
Giardia lamblia
Leishmania major
Thalassiosira pseudonana
Plasmodium falciparum
Cryptosporidium hominis
Cyanidioschyzon merolae
Arabidopsis thaliana
Oryza sativa
Dictyostelium discoideum
Schizosaccharomyces pombe
Saccharomyces cerevisiae
Saccharomyces gossypii
Tremelhedium bingsae
Caenorhabditis elegans
Caenorhabditis briggsae
Drosophila melanogaster
Anopheles gambiae
Danio rerio
Takifugu rubripes
Gallus gallus
Pan troglodytes
Homo sapiens
Mus musculus
Rattus norvegicus
Thermoanaerobact. tengcongensis
Clostridium acetobutylicum
Clostridium perfringens
Clostridium tetani
Phytoplasma Onion yellows
Mycoplasma mycoides
Mycoplasma pulmonis
Mycoplasma mobile
Ureaplasma parvum
Mycoplasma penetrans
M. gallisepticum
M. genitalium
M. pneumoniae
Lactobacillus plantarum
Lactobacillus johnsonii
Enterococcus faecalis
Lactococcus lactis
Streptococcus pneumoniae TIGR4
Streptococcus pneumoniae R6
Streptococcus mutans
Streptococcus agalactiae V
Streptococcus agalactiae III
Streptococcus pyogenes M1
Streptococcus pyogenes 8232
Streptococcus pyogenes SSI-1
Streptococcus pyogenes 315
Staphylococcus epidermidis
Staphylococcus aureus MW2
Staphylococcus aureus Mu50
Staphylococcus aureus N315
Listeria innocua
Listeria monocytogenes EGD
Listeria monocytogenes F2365
Bacillus halodurans
Bacillus subtilis
Oceanobacillus iheyensis
Bacillus anthracis
Bacillus cereus ATCC 10987
Bacillus cereus ATCC 14579
Rhodopirellula baltica
Gemmata obscuriglobus
Leptospira interrogans 56601
Leptospira interrogans L1-130
Borrelia burgdorferi
Treponema pallidum
Treponema denticola
Bifidobacterium longum
Tropheryma whipplei Twist
Tropheryma whipplei TW08/27
Streptomyces coelicolor
Streptomyces avermitilis
Corynebacterium diphtheriae
Corynebacterium efficiens
Corynebact. glutamicum
Corynebact. glutamicum 13032
Corynebacterium paratuberculosis
Mycobacterium leprae
Mycobacterium bovis
Mycobact. tuberculosis 1551
Mycobact. tuberculosis H37Rv
Fibrobacter succinogenes
Chlorobium tepidum
Porphyromonas gingivalis
Bacteroides thetaiotaomicron
Chlamydia trachomatis
Chlamydia muridarum
Chlamydophila caviae
Chlamydia pneumoniae 1138
Chlamydia pneumoniae AR39
Chlamydia pneumoniae CWL029
Chlamydia pneumoniae J138
Fusobacterium nucleatum
Thermotoga maritima
Aquifex aeolicus
Deinococcus radiodurans
Thermus thermophilus
Deinococcus geothermalis
Dehalococcoides ethenogenes
Gloeobacter violaceus
Thermosynechococcus elongatus
Nostoc sp. PCC7120
Synechocystis sp. PCC6803
Prochlorococcus marinus SS120
Prochlorococcus marinus MED4
Prochlorococcus marinus MIT9313
Prochlorococcus sp. MED4
Synechococcus sp. WH8102
Acidobacterium capsulatum
Solibacter usitatus
Geobacter sulfurreducens
Bdellovibrio bacteriovorus
Desulfovibrio vulgaris
Wolinella succinogenes
Campylobacter jejuni
Helicobacter hepaticus
Helicobacter pylori 26695
Helicobacter pylori J99
Wolbachia sp. wMel
Rickettsia conorii
Rickettsia prowazekii
Caulobacter crescentus
Bradyrhizobium japonicum
Rhodopseudomonas palustris
Mesorhizobium loti
Brucella melitensis
Brucella suis
Sinorhizobium meliloti
Agrobacterium tumefaciens W.
Agrobacterium tumefaciens C.
Nitrosomonas europaea
Chromobacterium violaceum
Neisseria meningitidis B
Neisseria meningitidis A
Ralstonia solanacearum
Bordetella pertussis
Bordetella bronchiseptica
Bordetella parapertussis
Coxiella burnetii
Xanthomonas campestris
Xanthomonas axonopodis
Xylella fastidiosa 9a5c
Xylella fastidiosa 700964
Pseudomonas aeruginosa
Pseudomonas syringae
Pseudomonas putida
Shewanella oneidensis
Photobacterium profundum
Vibrio cholerae
Vibrio parahaemolyticus
Vibrio vulnificus CMCP6
Vibrio vulnificus YJ016
Haemophilus ducreyi
Haemophilus influenzae
Pasteurella multocida
W. brevipalpis
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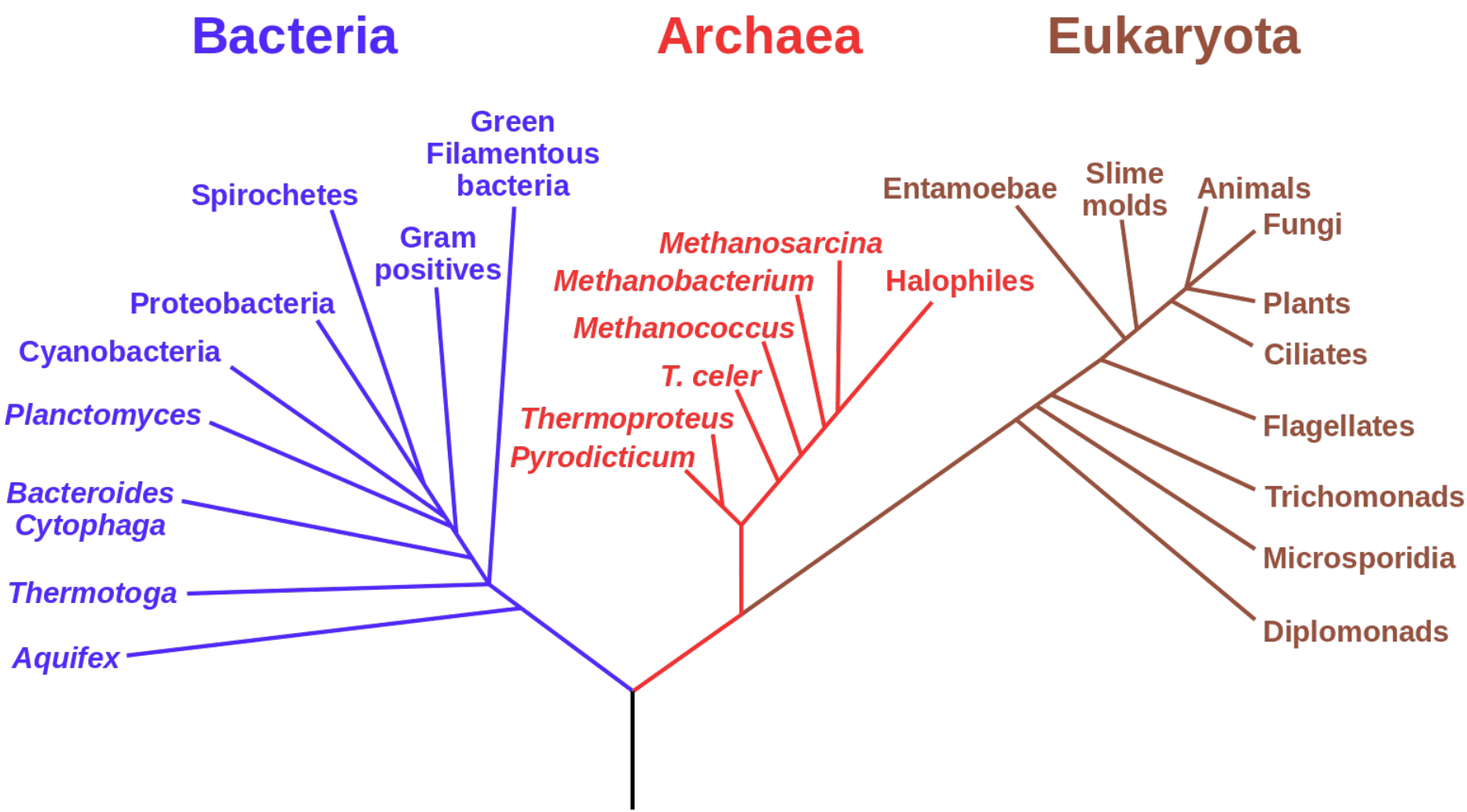
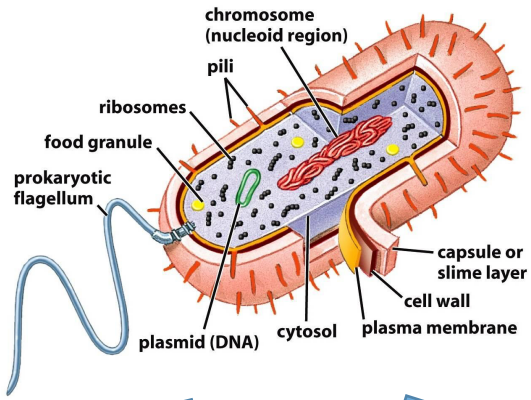
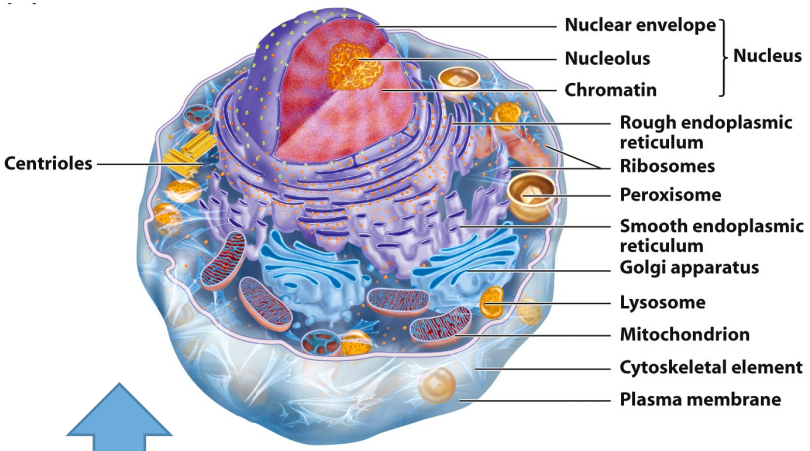
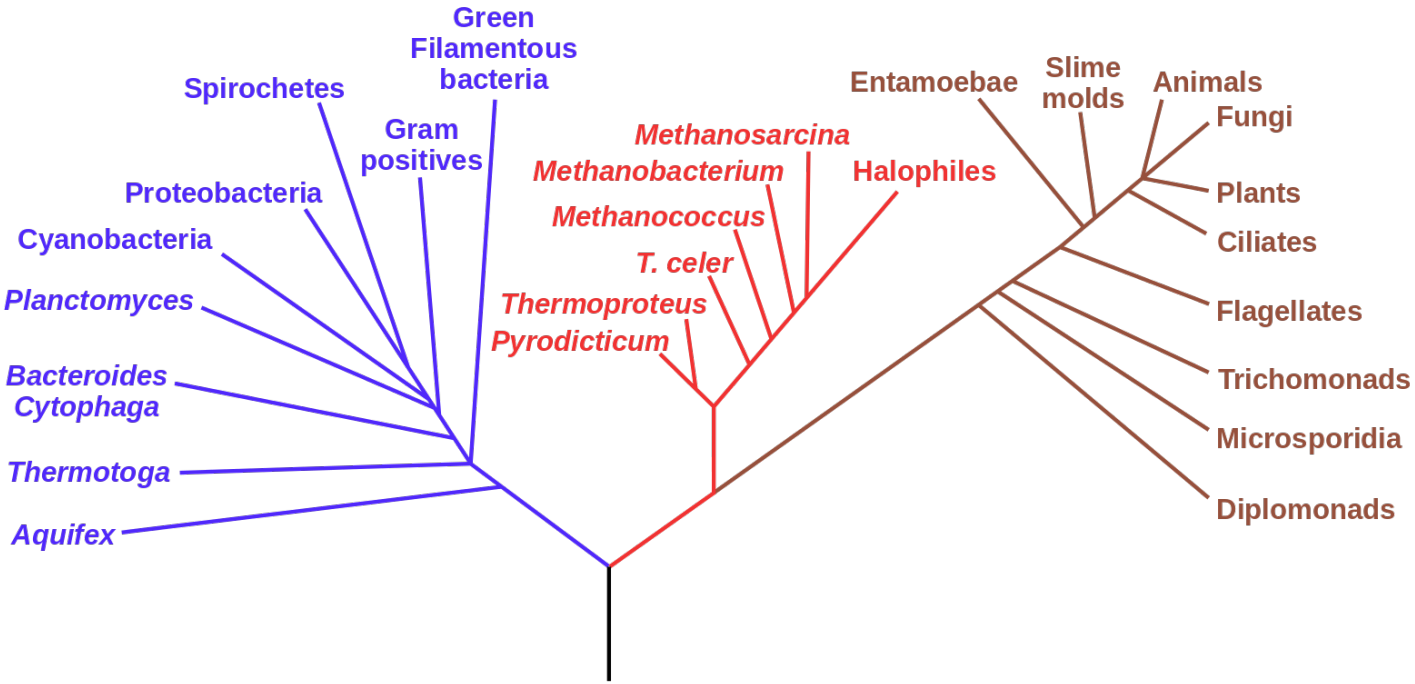
Phylogenetic Tree of Life



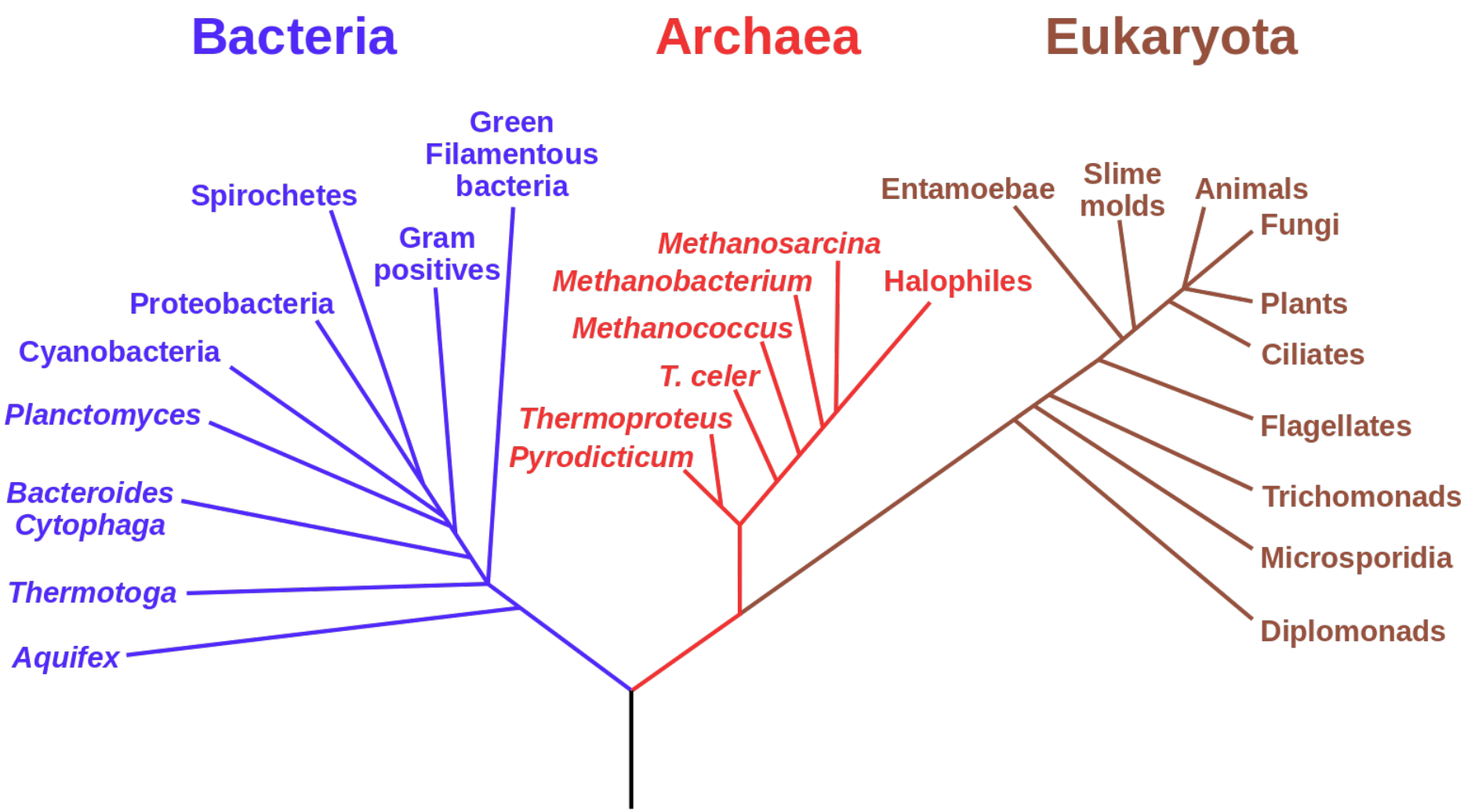




Bacteria **Archaea** **Eukaryota**

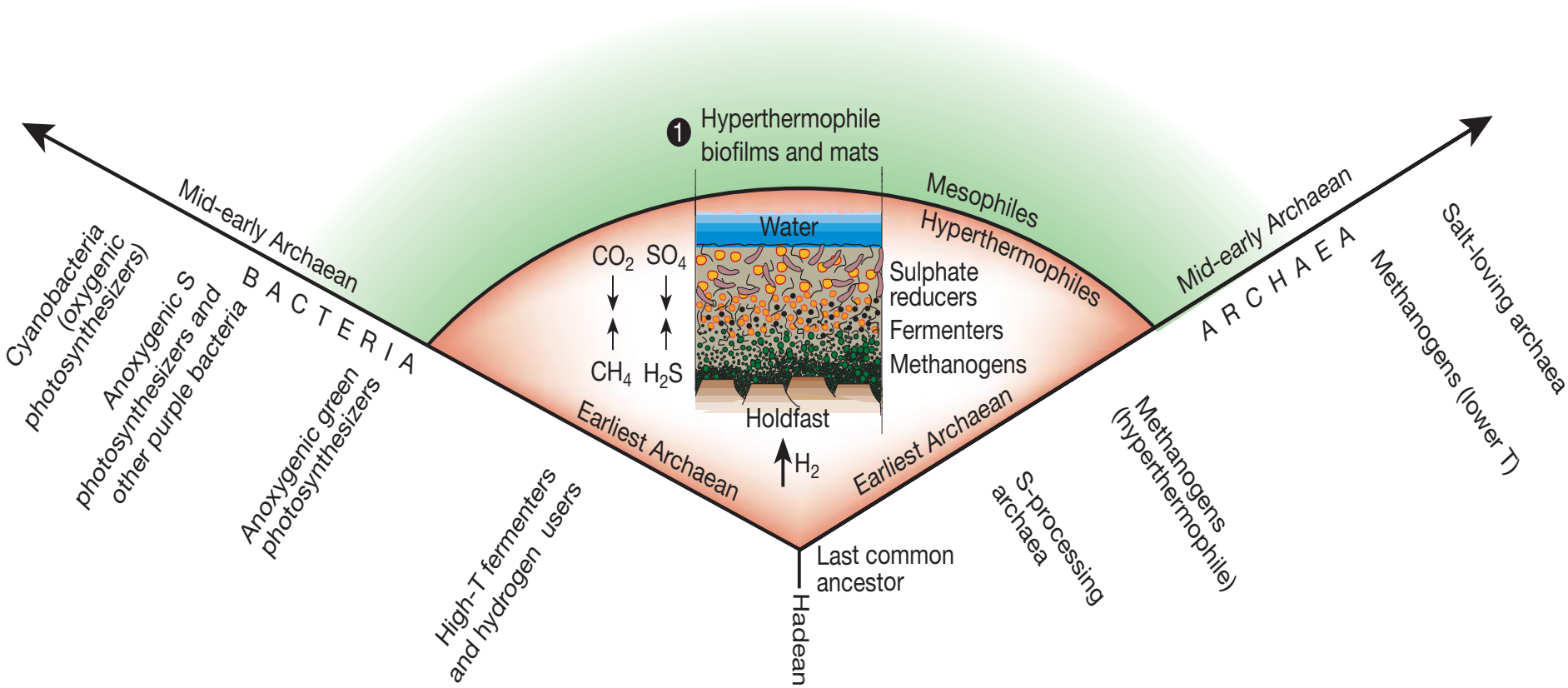


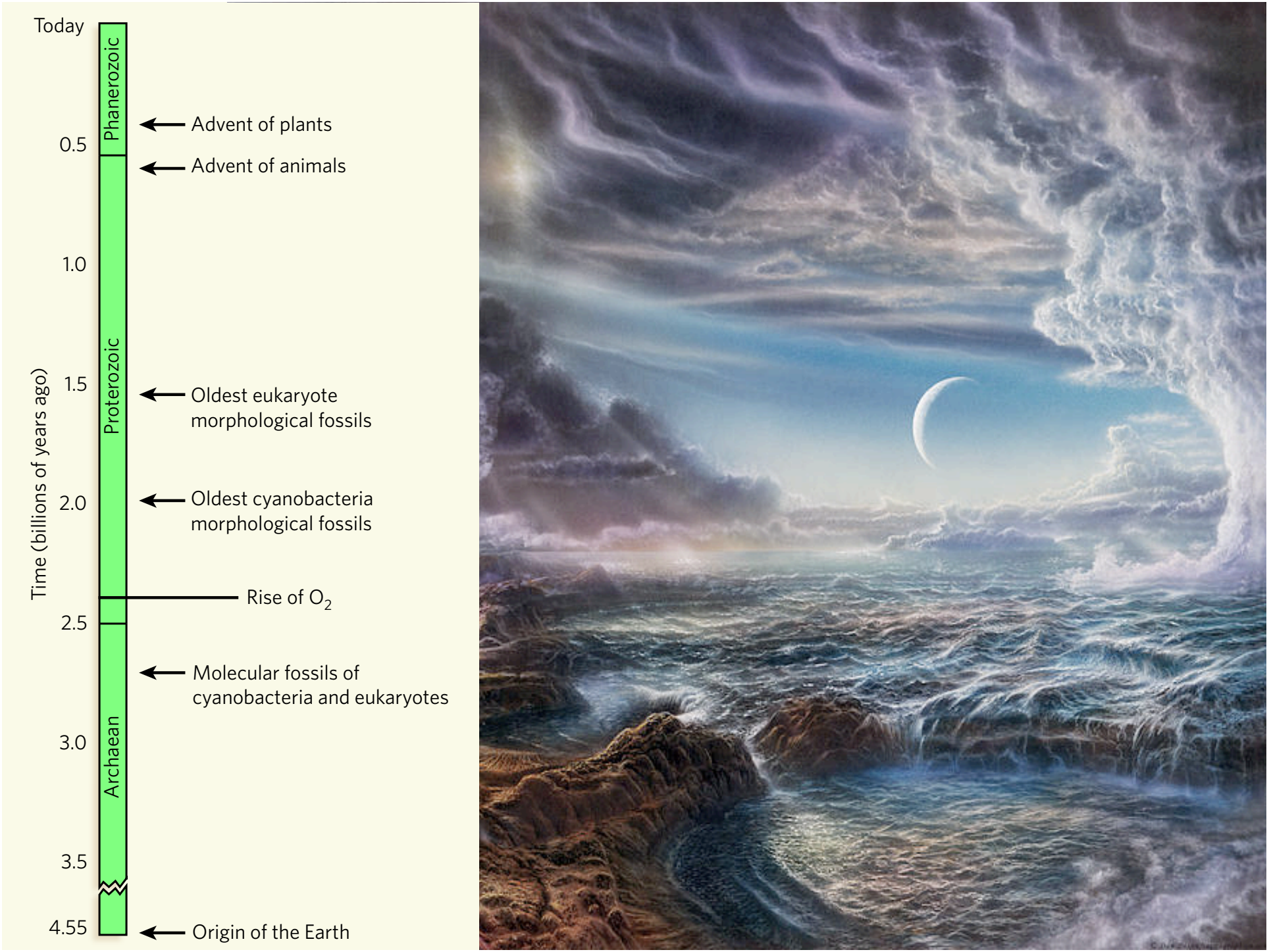
Phylogenetic Tree of Life

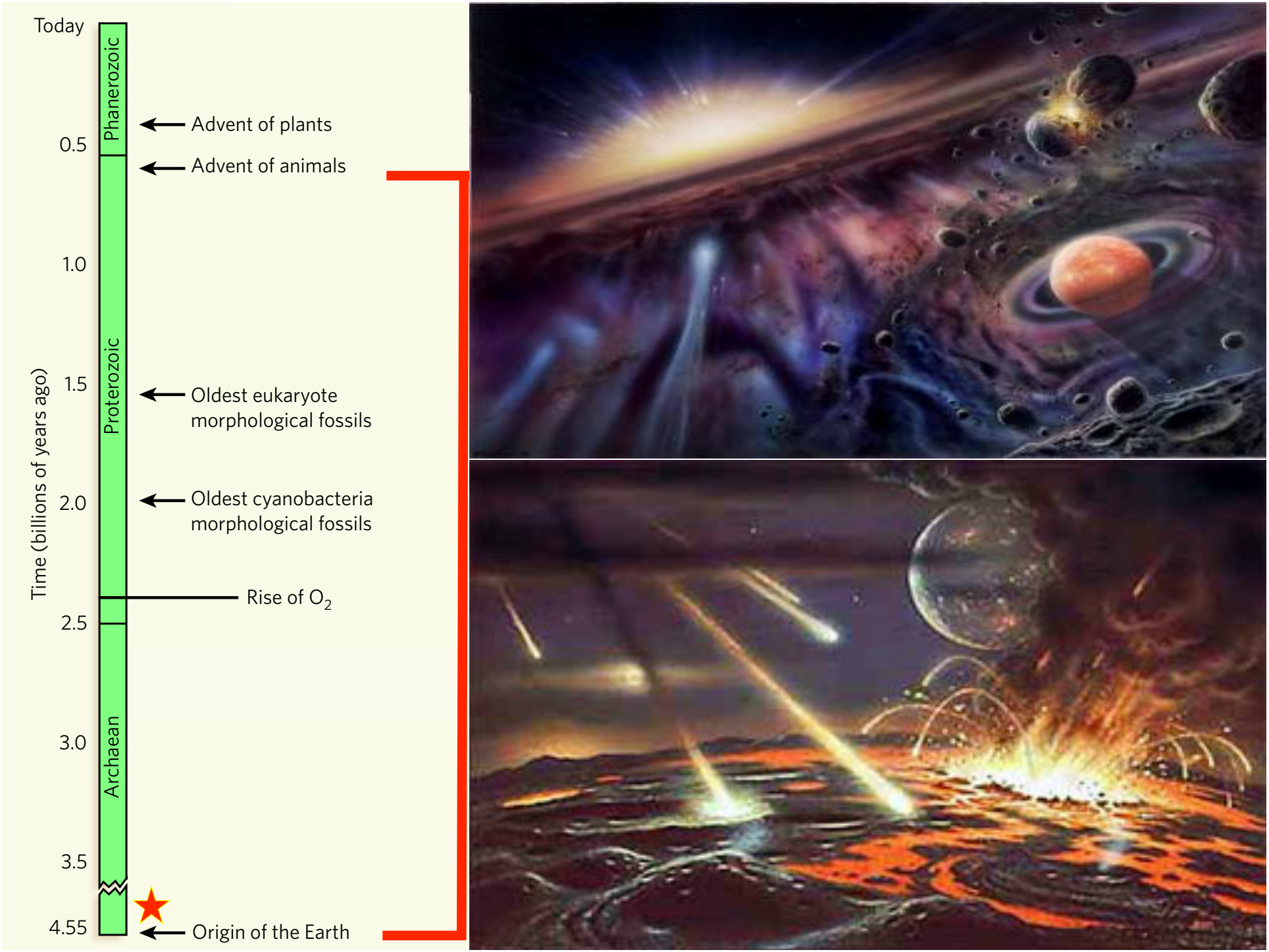


The habitat and nature of early life

E. G. Nisbet* & N. H. Sleep†




Today
Phanerozoic
Proterozoic
Archaean
Time (billions of years ago)
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.55
Advent of plants
Advent of animals
Oldest eukaryote morphological fossils
Oldest cyanobacteria morphological fossils
Rise of O_2
Molecular fossils of cyanobacteria and eukaryotes
Origin of the Earth


Today
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0.5
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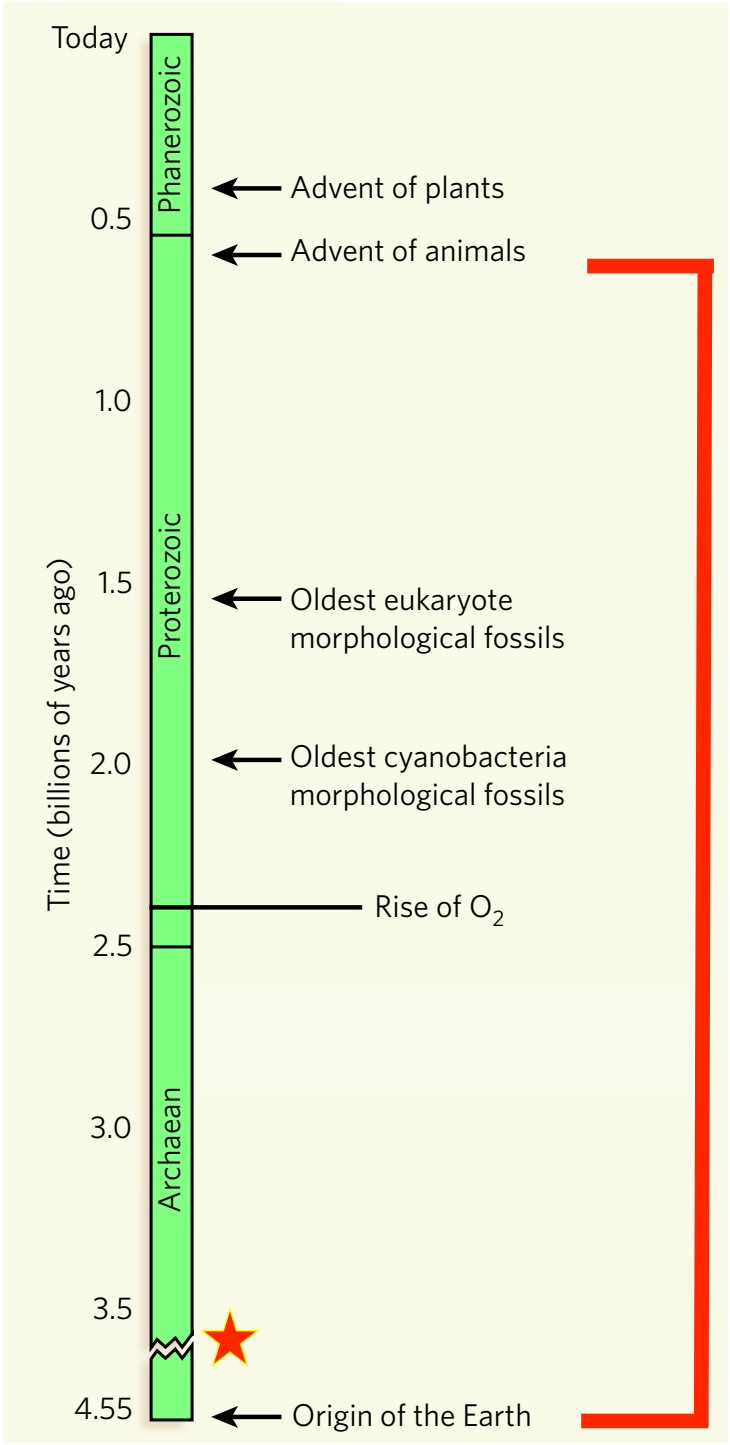
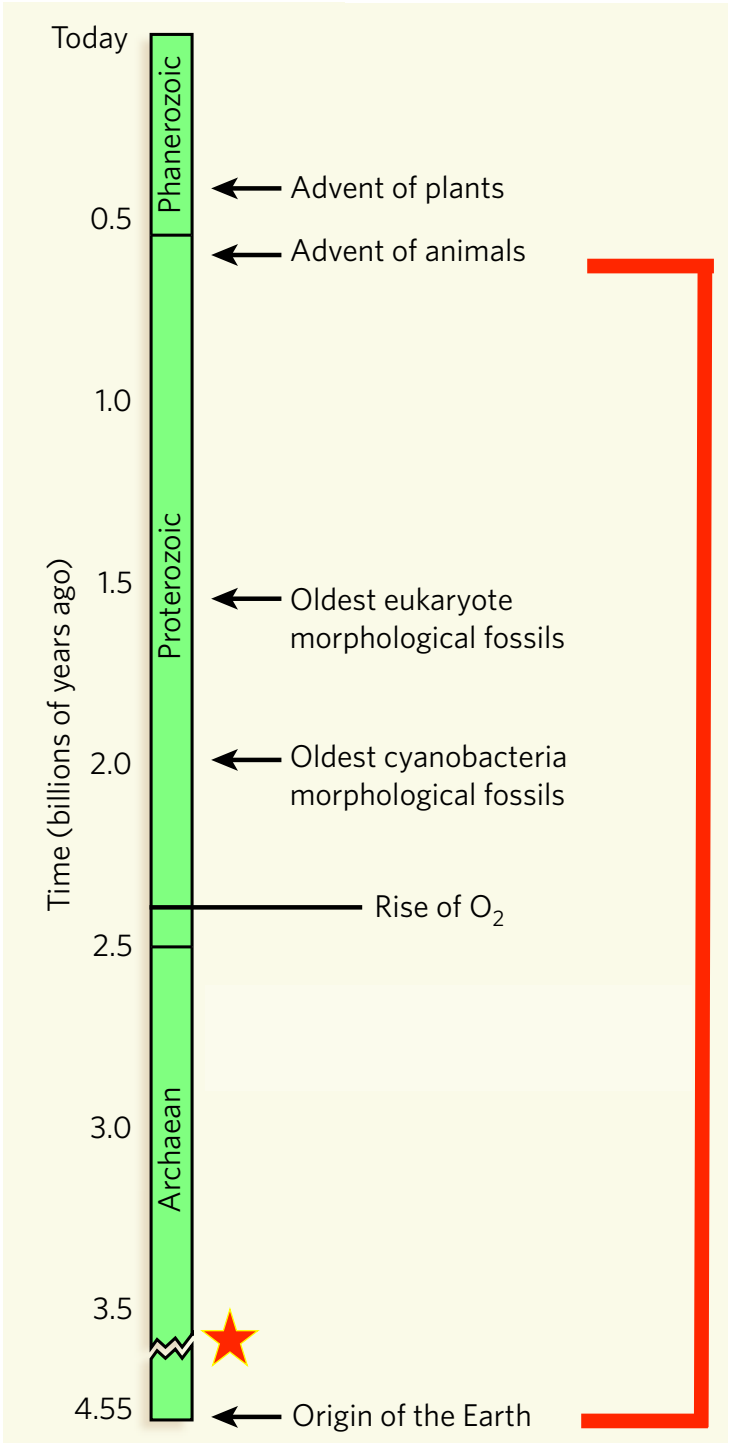
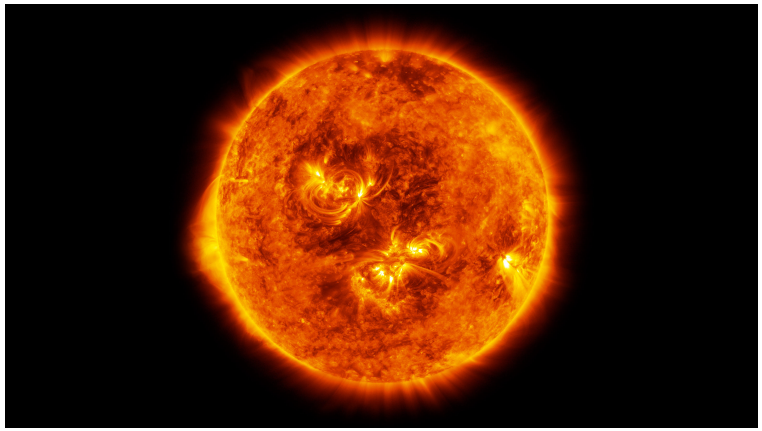
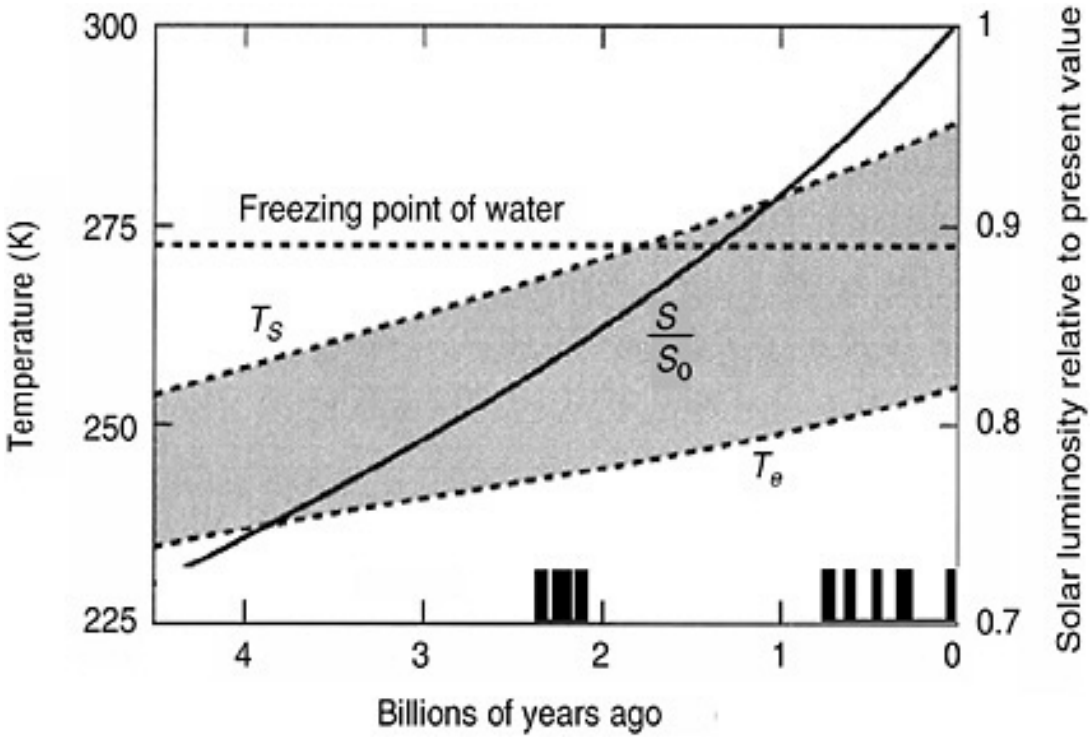
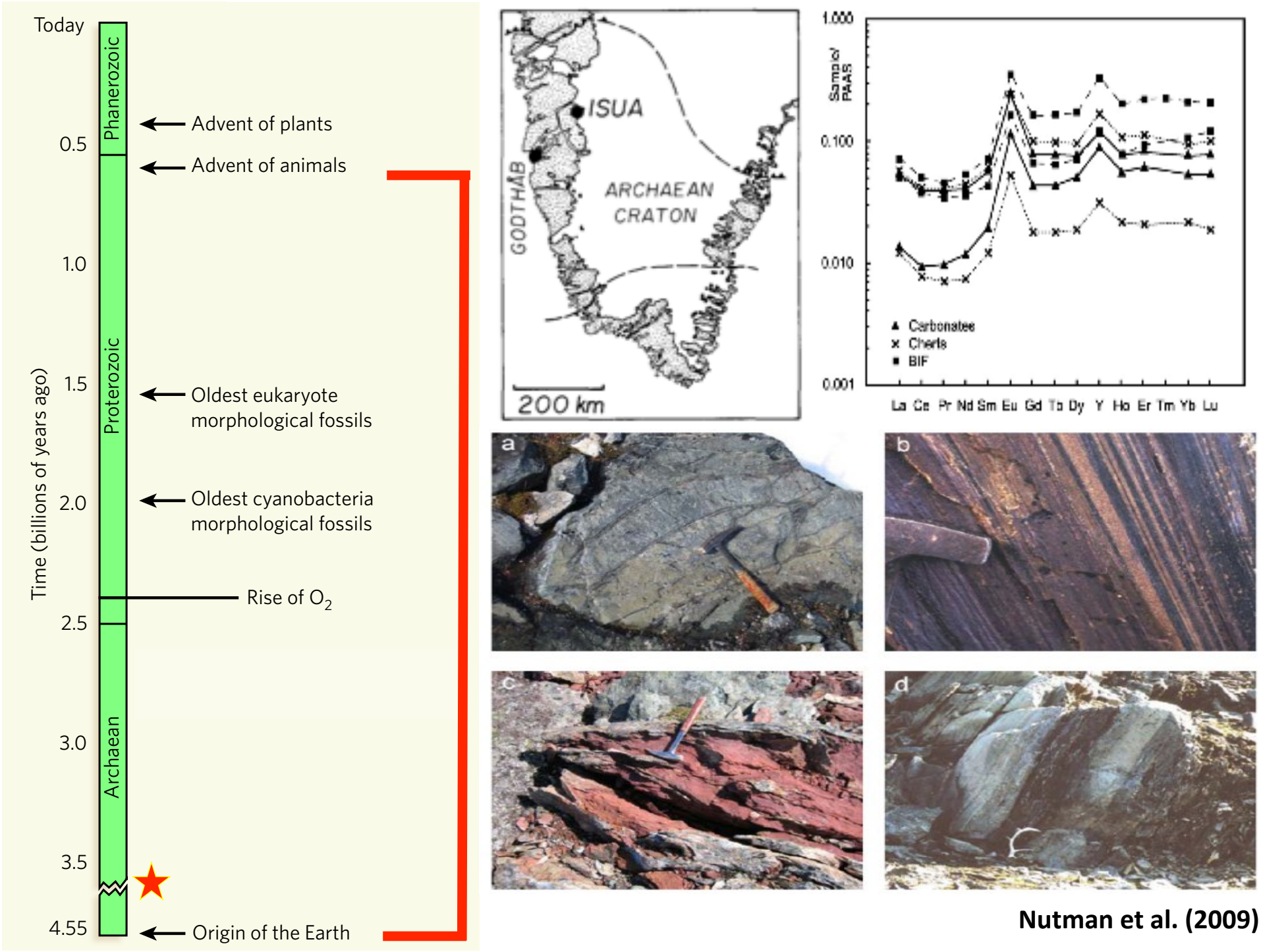

Today
Phanerozoic
Proterozoic
Archaean
Time (billions of years ago)
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.55
Advent of plants
Advent of animals
Oldest eukaryote morphological fossils
Oldest cyanobacteria morphological fossils
Rise of O_2
Origin of the Earth

Le paradoxe du jeune soleil faible

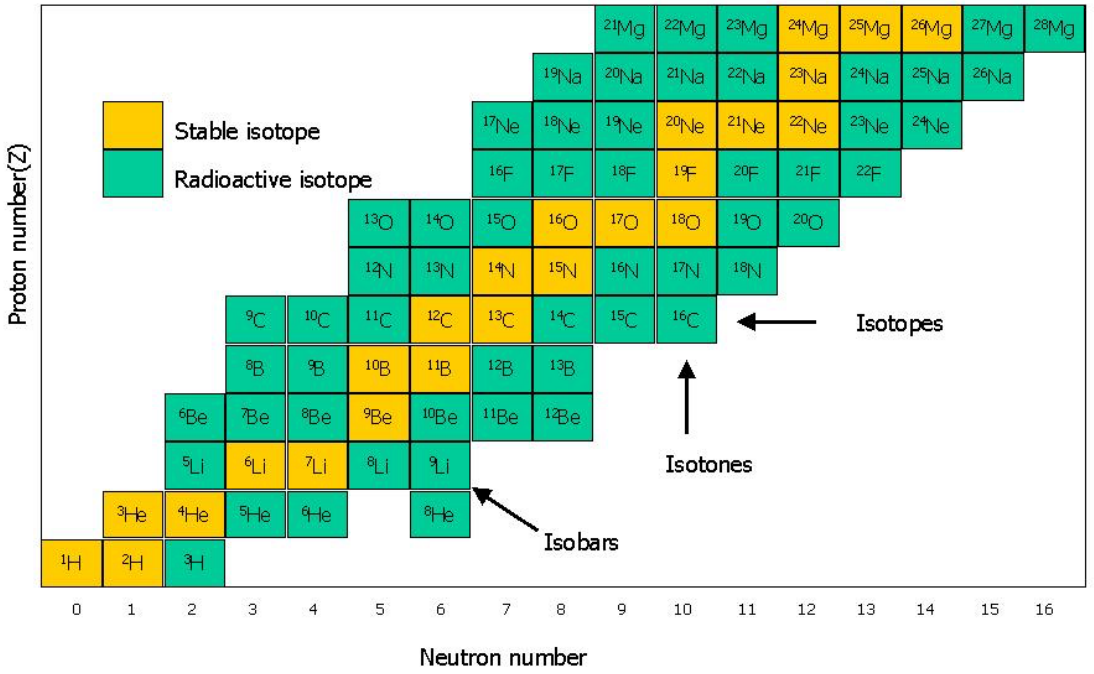




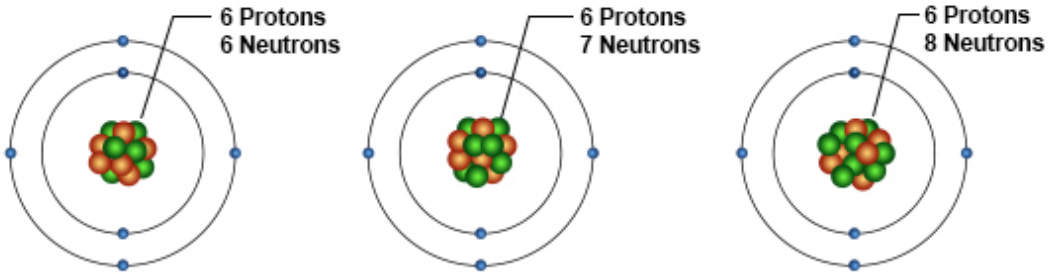




Nutman et al. (2009)



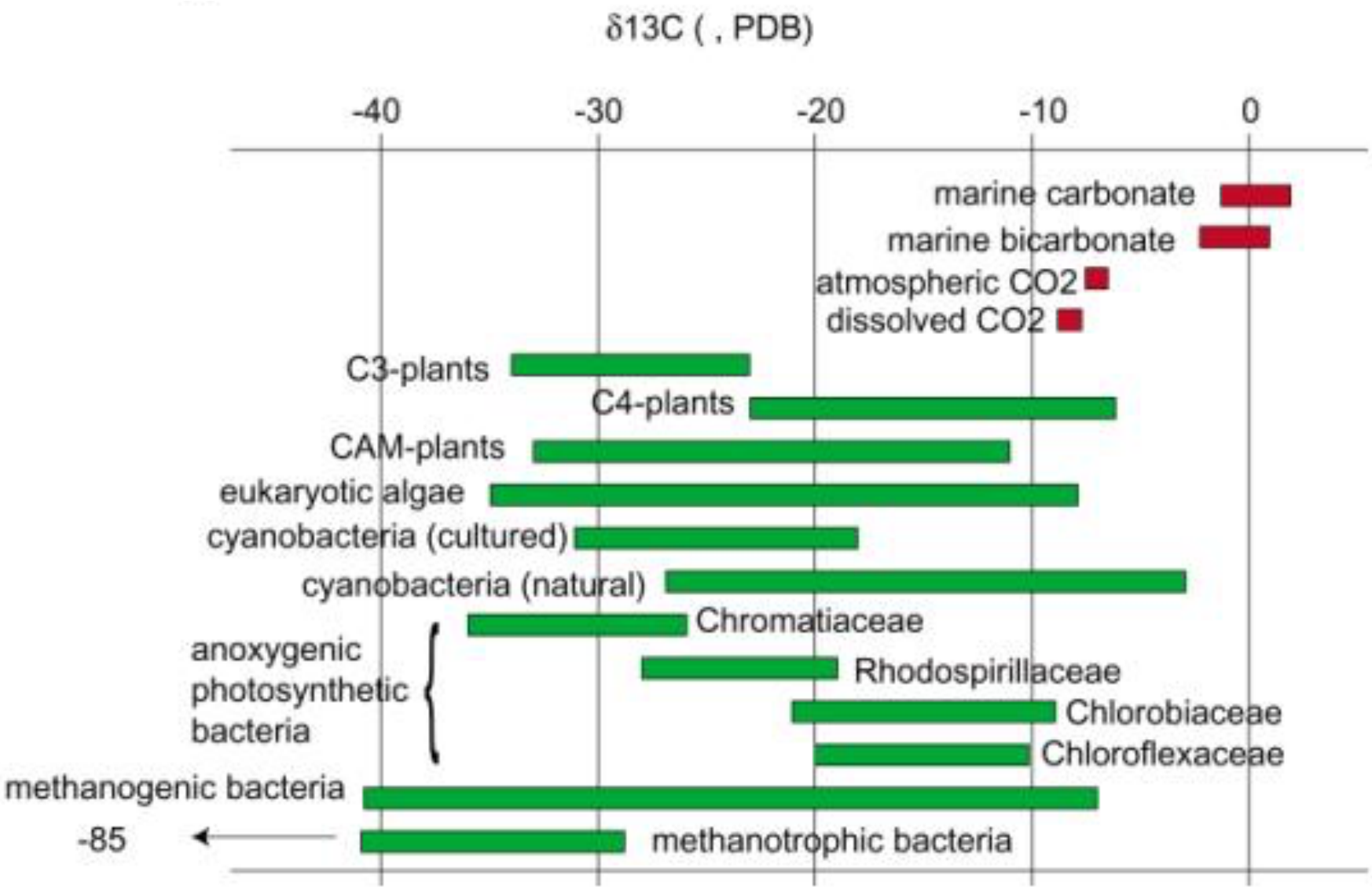
Natural Isotopes of Carbon

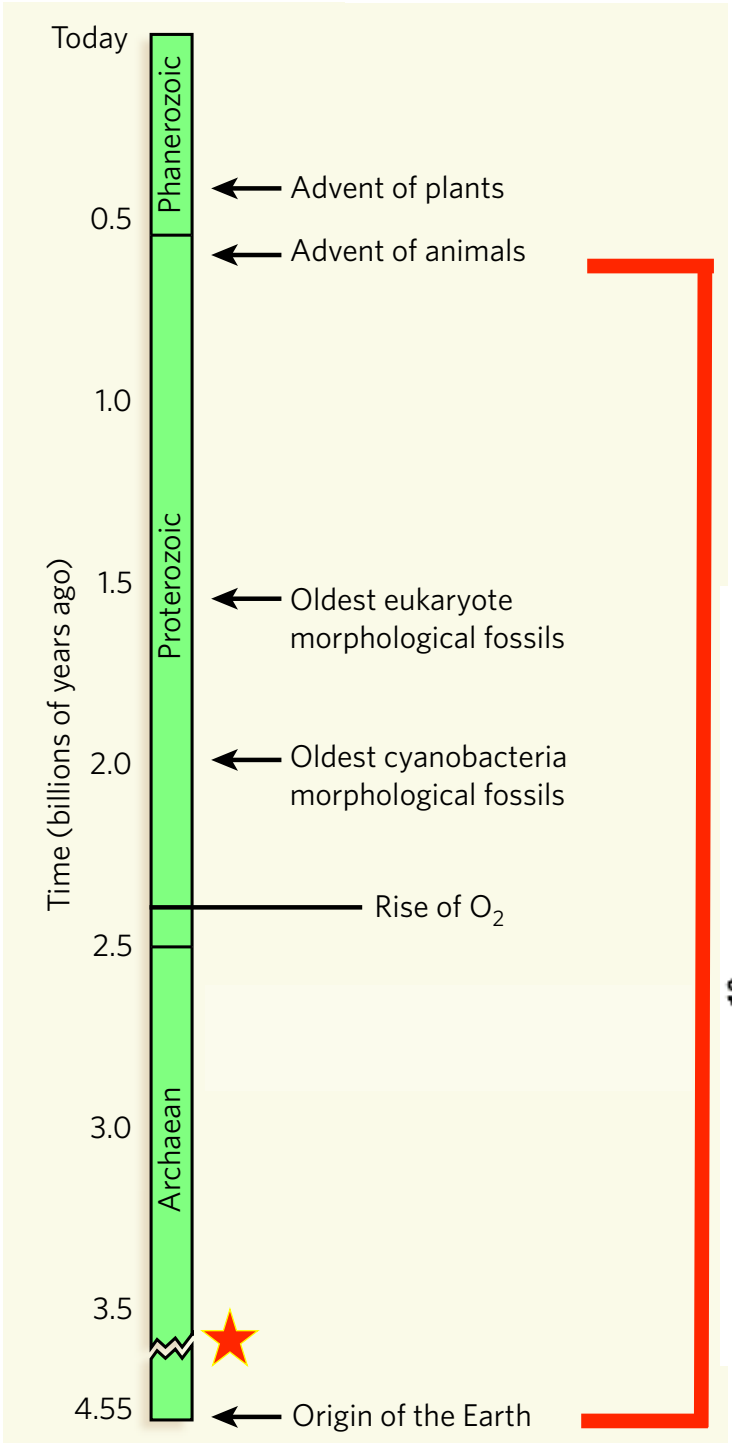


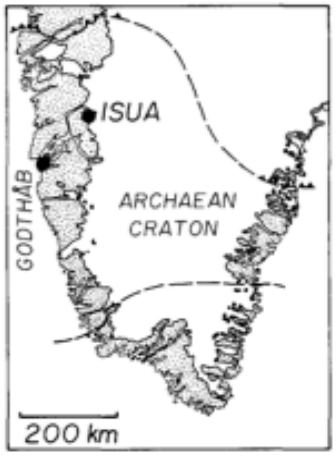
Carbon-12
(6P + 6N)
Atomic Weight = 12
Isotope Mass: 12 u
Abundance: 98.89%

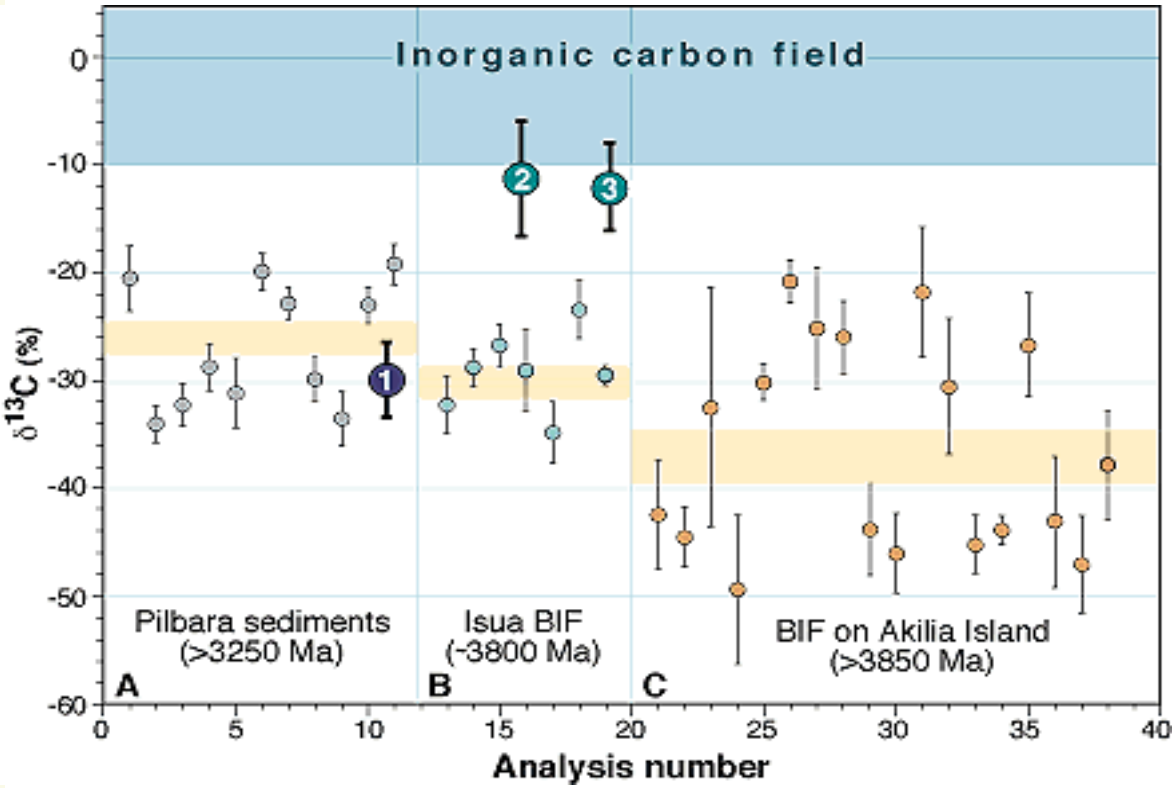
Carbon-13
(6P + 7N)
Atomic Weight = 13
Atomic Mass = 13.00335 u
Abundance: 1.109%

Carbon-14
(6P + 8N)
Atomic Weight = 14
Isotope Mass: 14.003241 u
Abundance: 1 Part Per Trillion
Half-life: 5,730 ± 40 Years

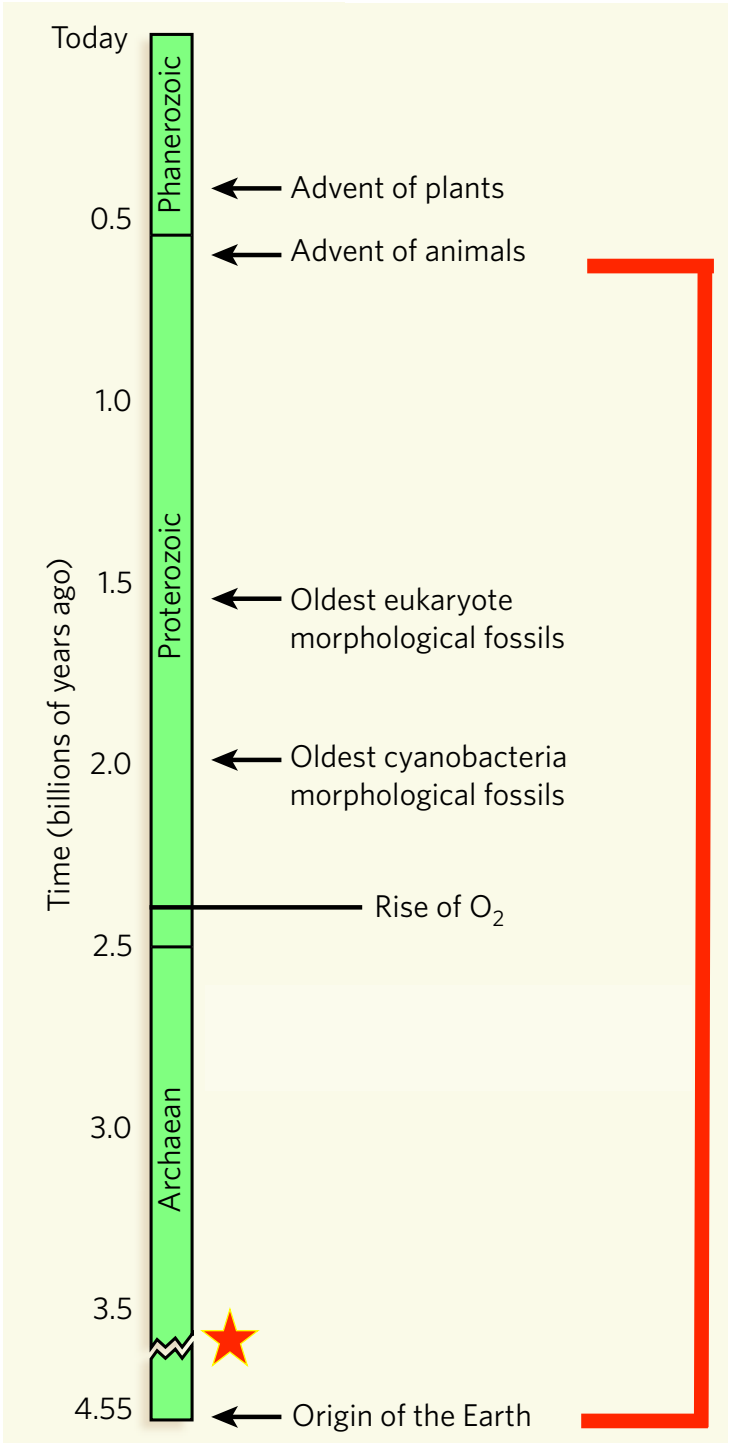

δ13C (, PDB)
-40
-30
-20
-10
0
marine carbonate
marine bicarbonate
atmospheric CO2
dissolved CO2
C3-plants
C4-plants
CAM-plants
eukaryotic algae
cyanobacteria (cultured)
cyanobacteria (natural)
Chromatiaceae
anoxygenic photosynthetic bacteria
Rhodospirillaceae
Chlorobiaceae
Chloroflexaceae
methanogenic bacteria
-85
methanotrophic bacteria







Holland (1997)

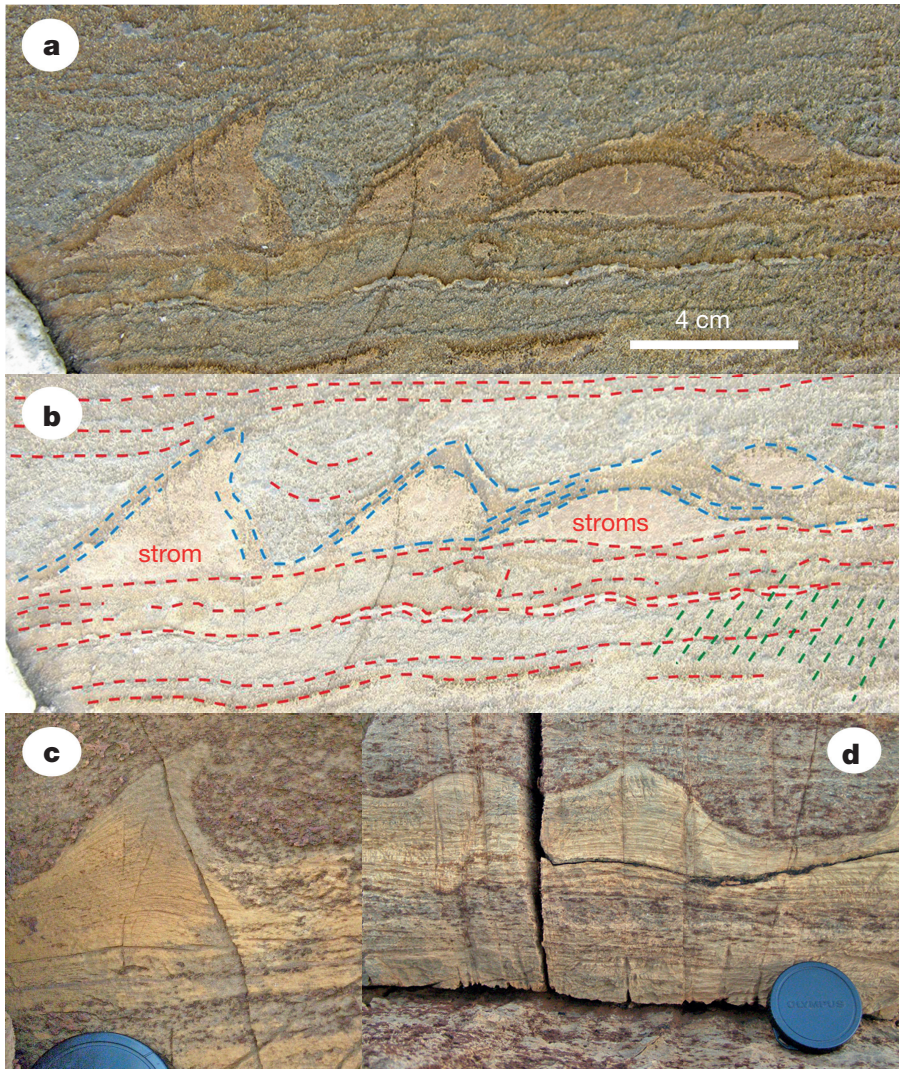


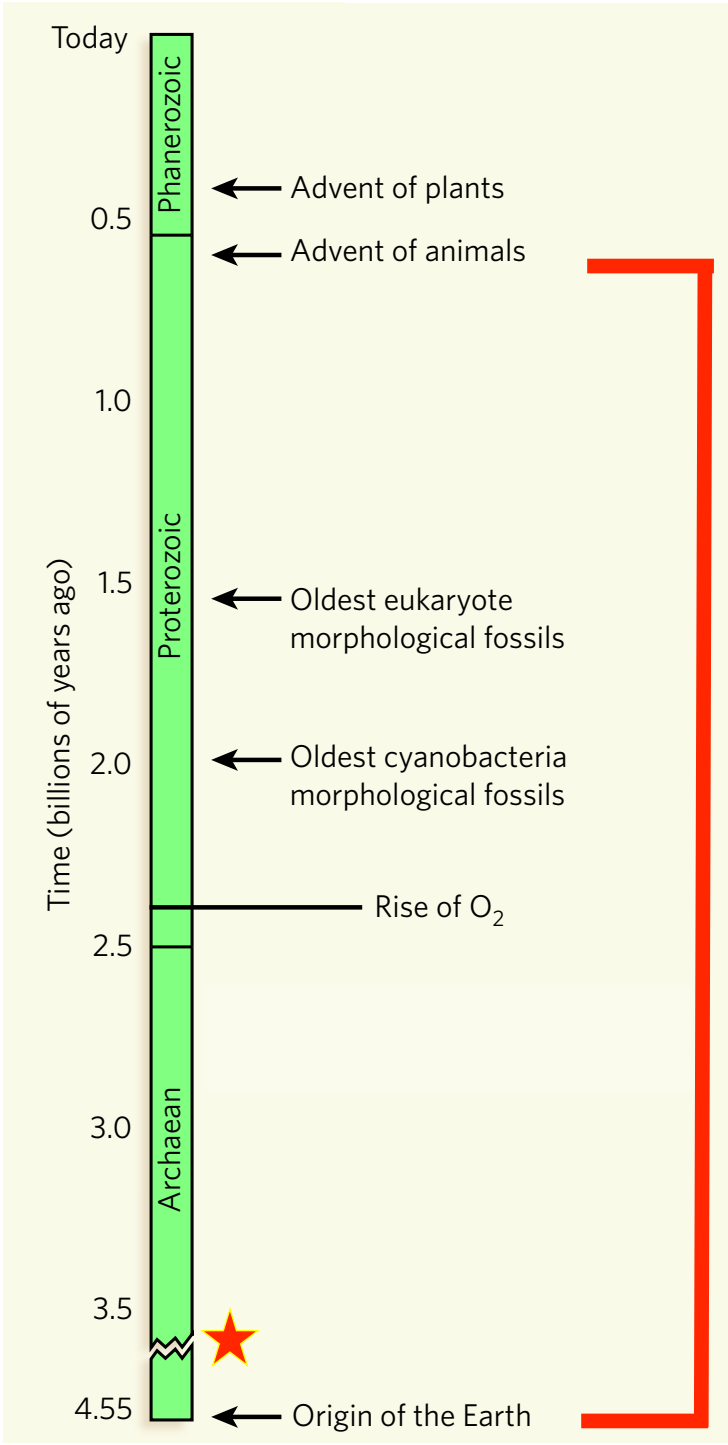
LETTER

doi:10.1038/nature19355

Rapid emergence of life shown by discovery of 3,700-million-year-old microbial structures

Allen P. Nutman[1,2], Vickie C. Bennett[3], Clark R. L. Friend[4], Martin J. Van Kranendonk[2,5,6] & Allan R. Chivas[1]





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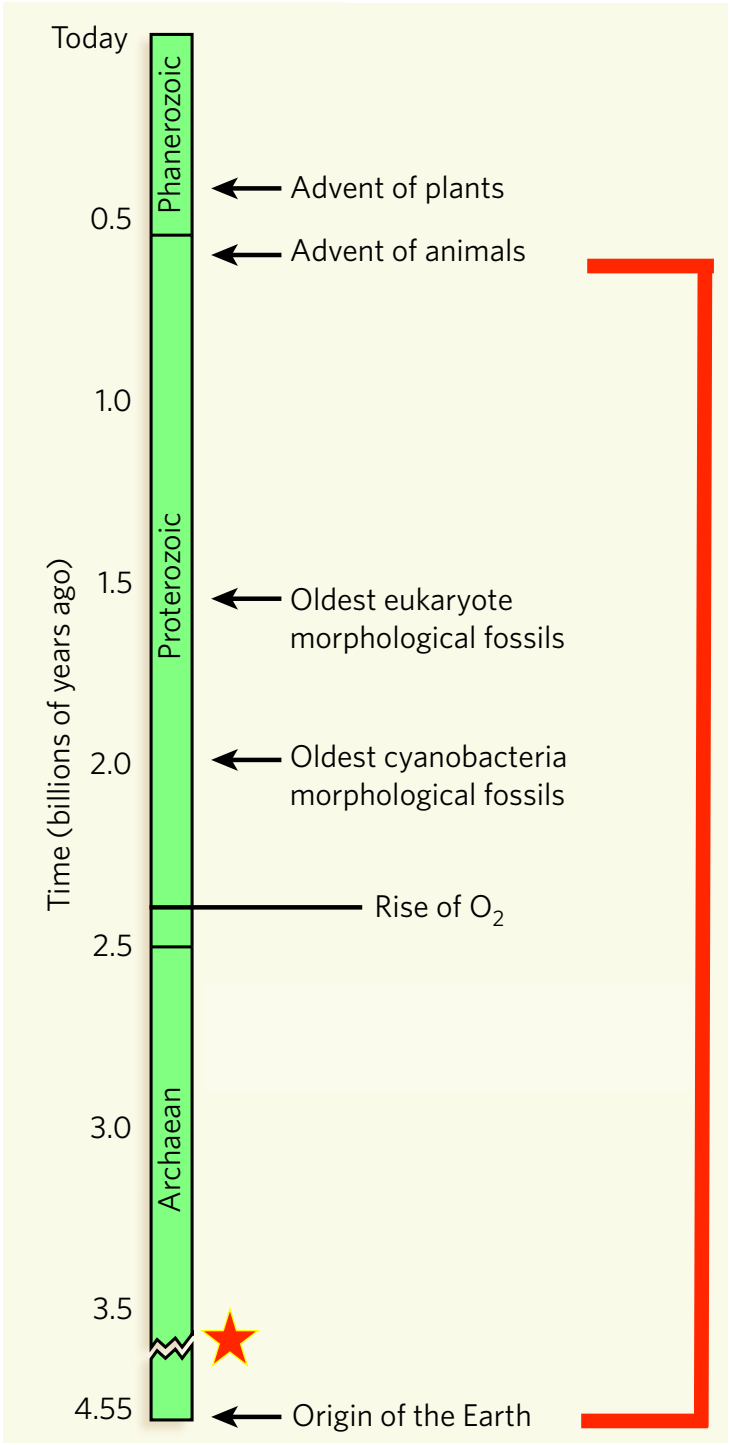

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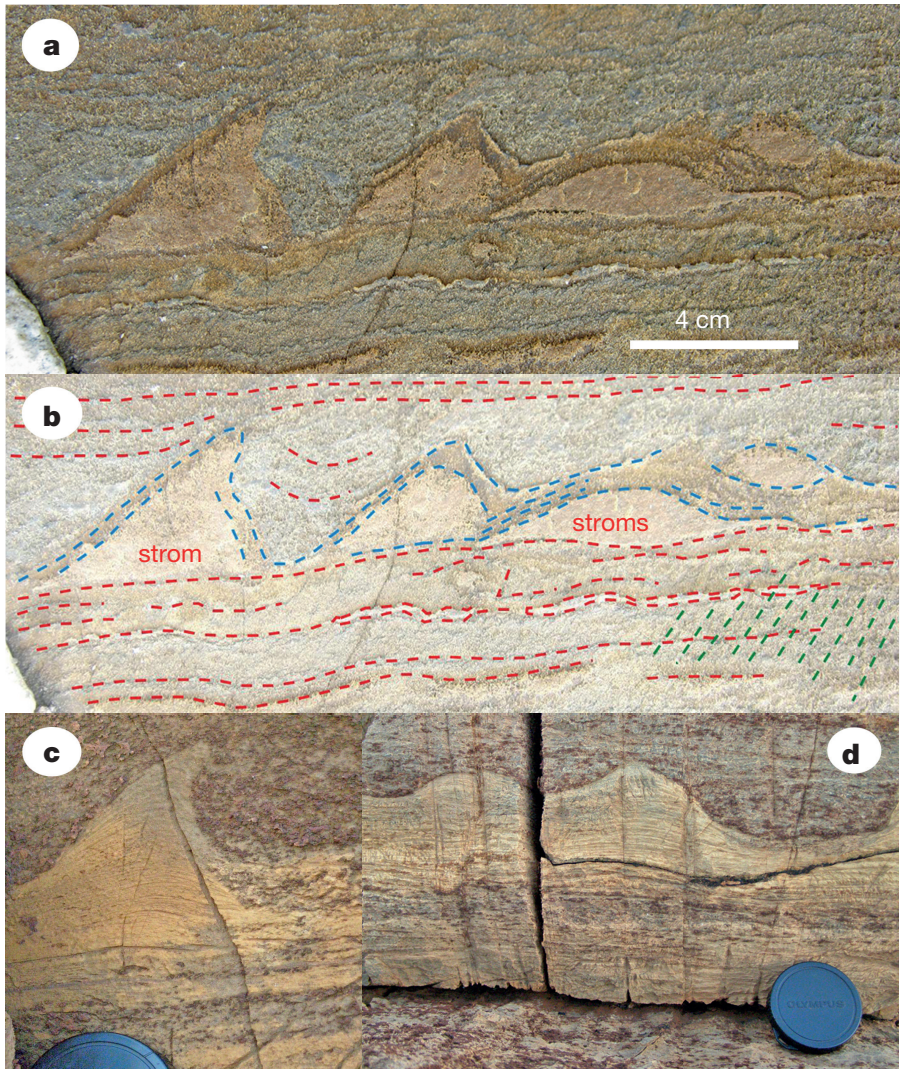
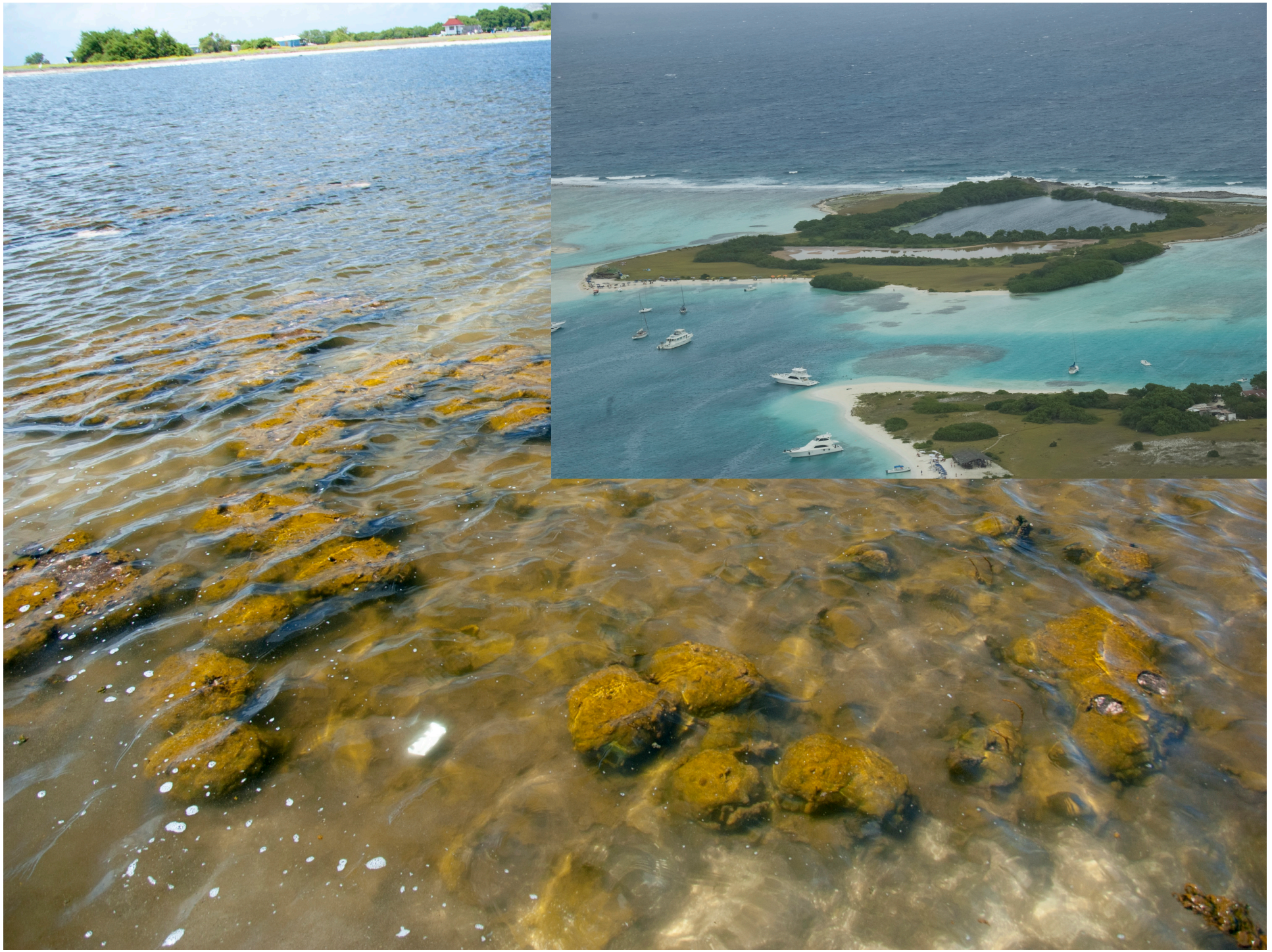
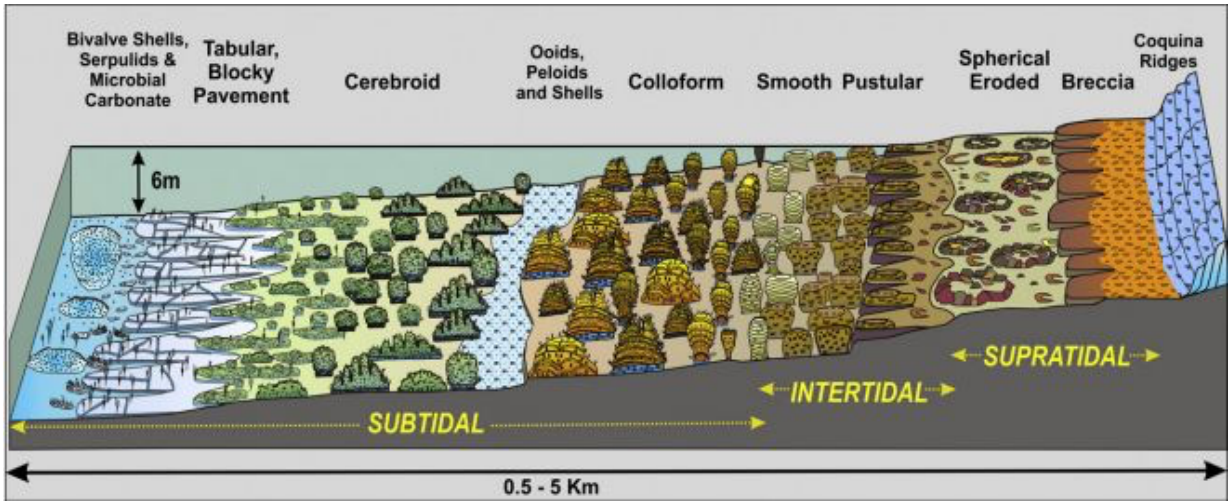
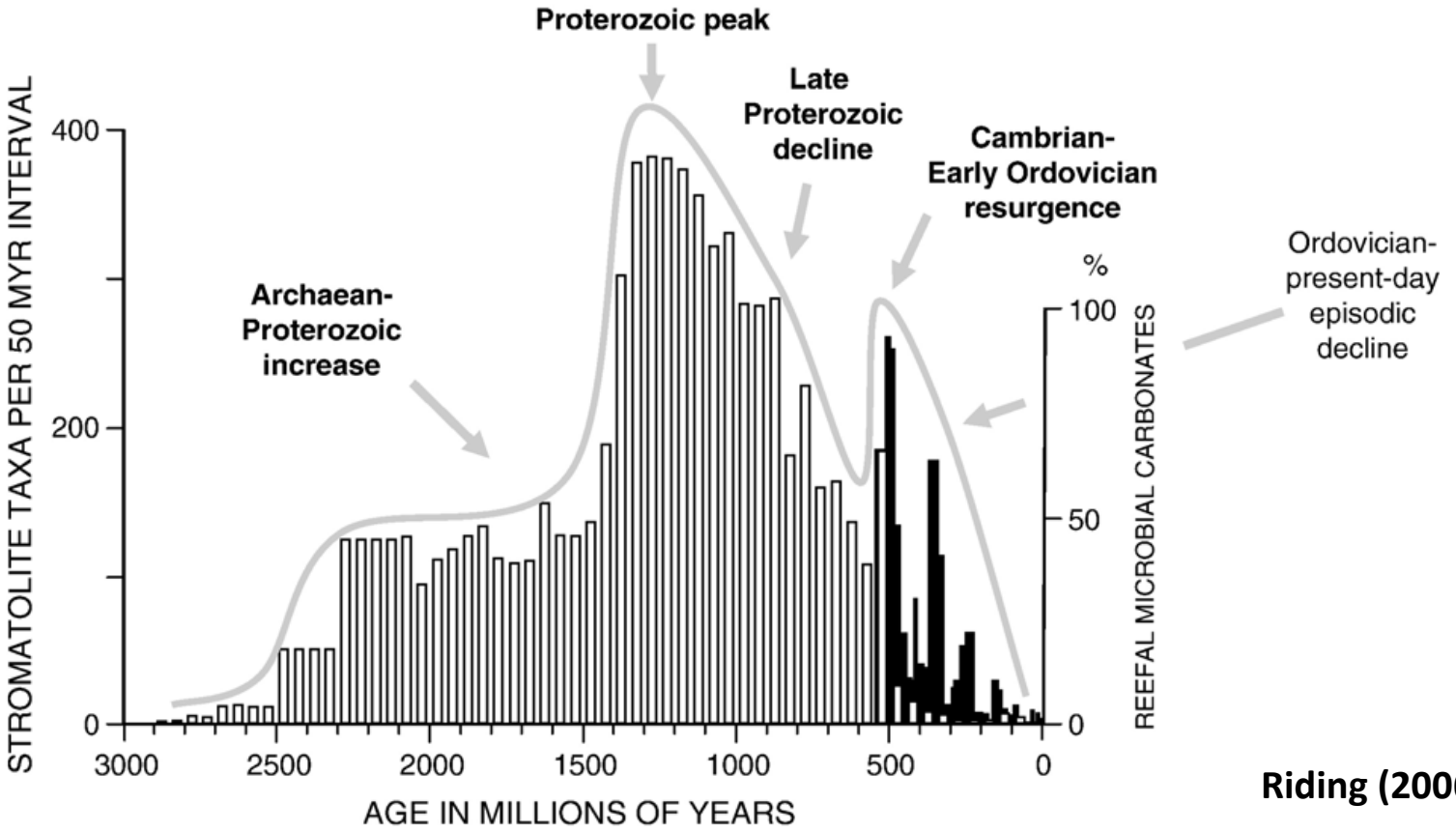


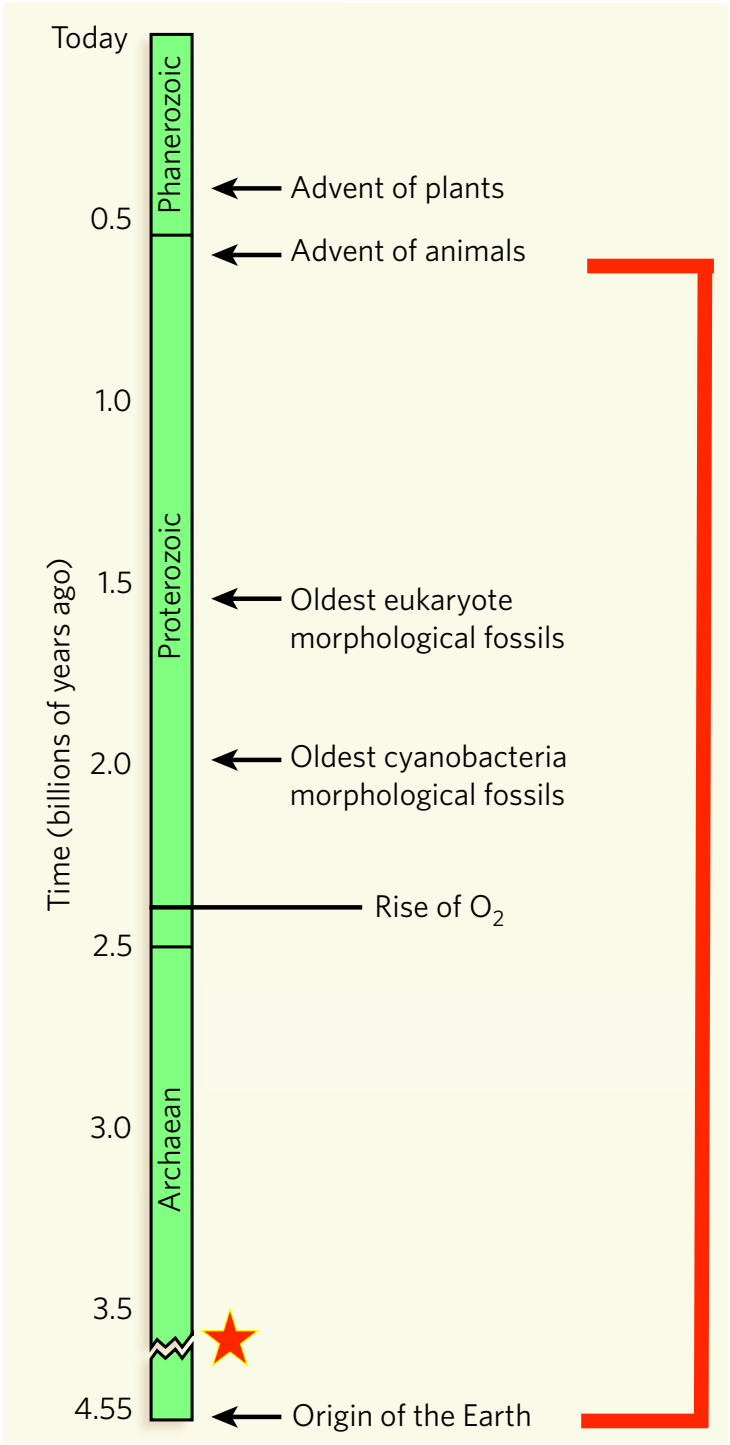


ERCB
AGS


Bivalve Shells, Serpulids & Microbial Carbonate
Tabular, Blocky Pavement
Cerebroid
Ooids, Peloids and Shells
Colloform
Smooth Pustular
Spherical Eroded
Breccia
Coquina Ridges
6m
SUPRATIDAL
INTERTIDAL
SUBTIDAL
0.5 - 5 Km


Proterozoic peak
Late Proterozoic decline
Cambrian-Early Ordovician resurgence
Archaean-Proterozoic increase
Ordovician-present-day episodic decline
STROMATOLITE TAXA PER 50 MYR INTERVAL
400
200
0
%
100
50
0
REEFAL MICROBIAL CARBONATES
3000
2500
2000
1500
1000
500
0
AGE IN MILLIONS OF YEARS

Riding (2006)



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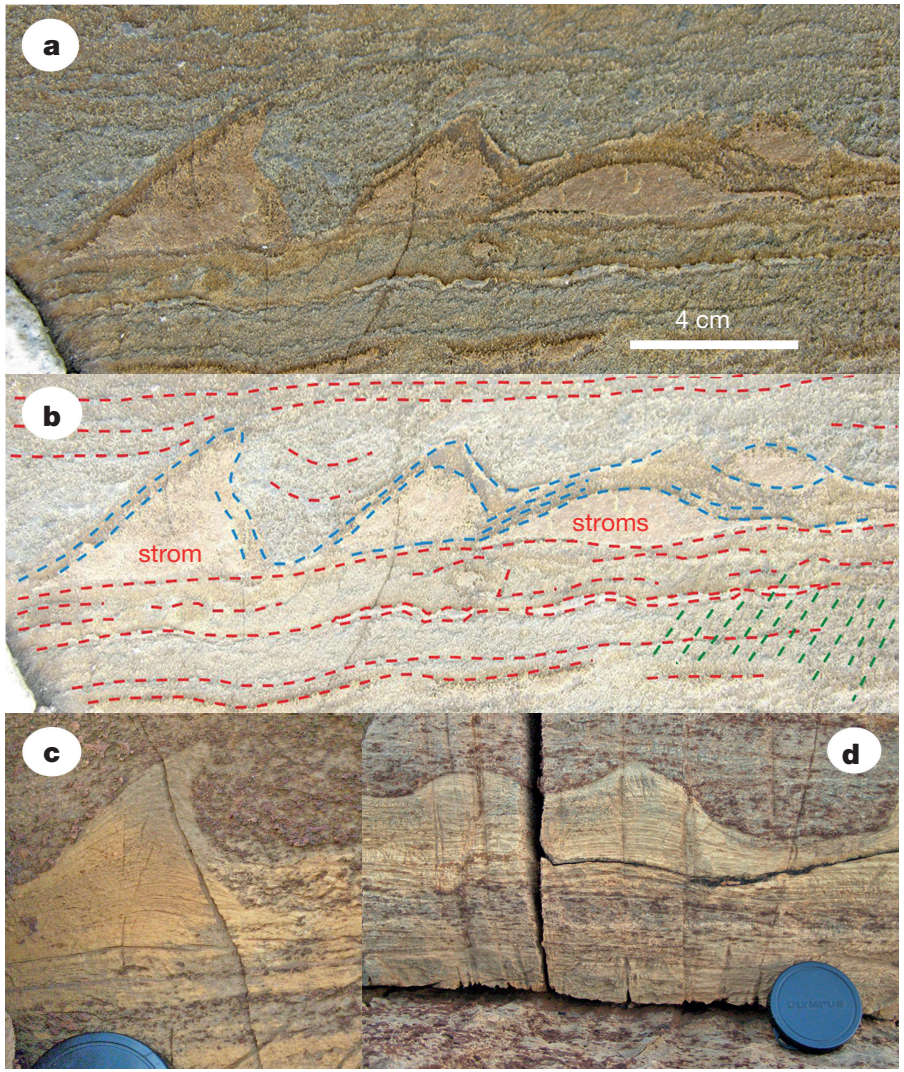
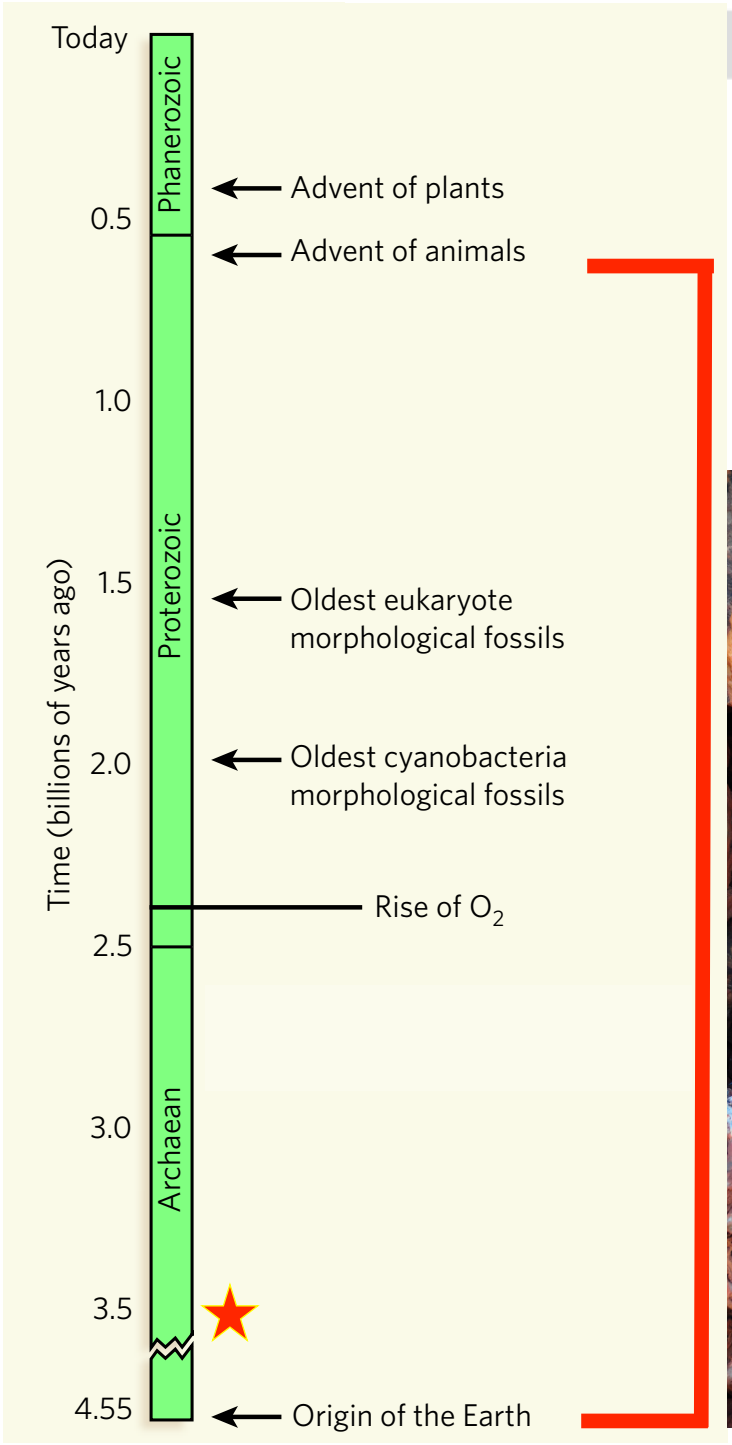


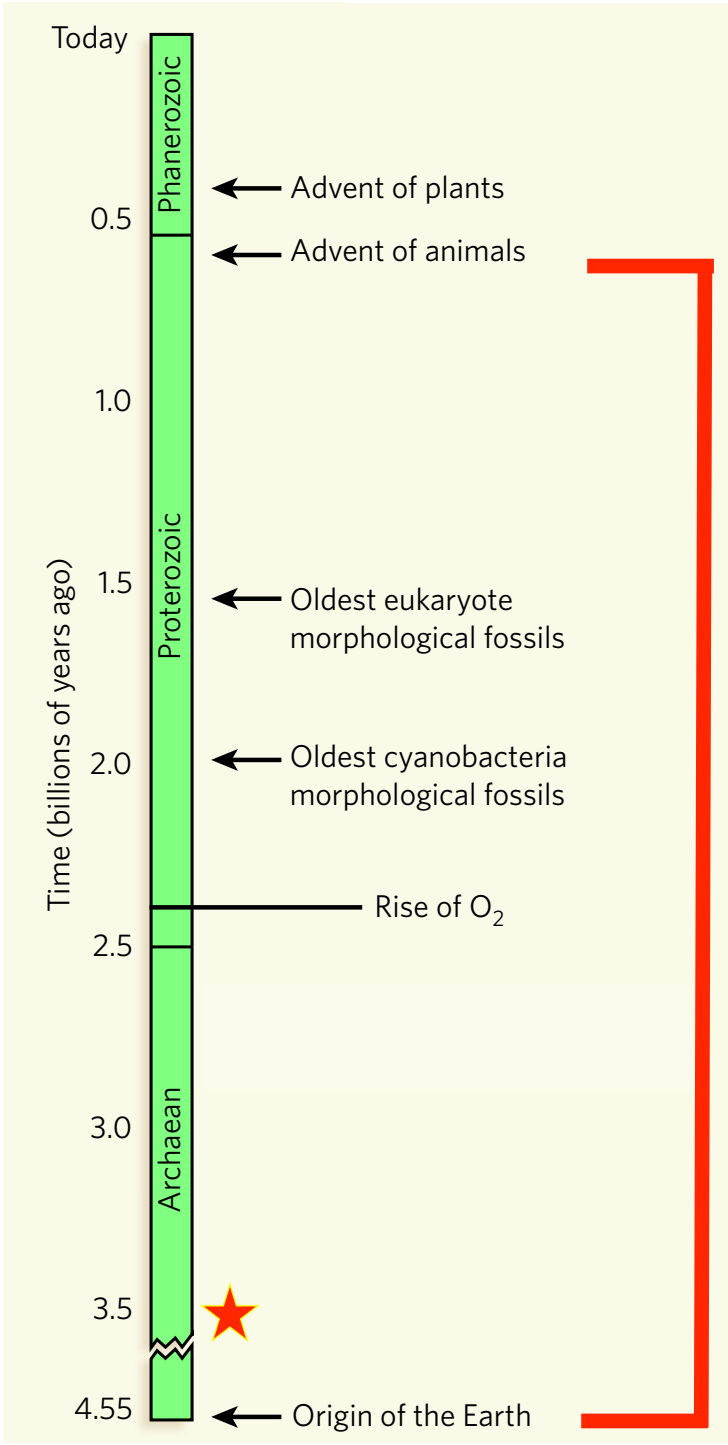


nature Vol 441|8 June 2006|doi:10.1038/nature04764

ARTICLES

Stromatolite reef from the Early Archaean era of Australia

Abigail C. Allwood[1,2], Malcolm R. Walter[1,2], Balz S. Kamber[3], Craig P. Marshall[1,4] & Ian W. Burch[2]


Today
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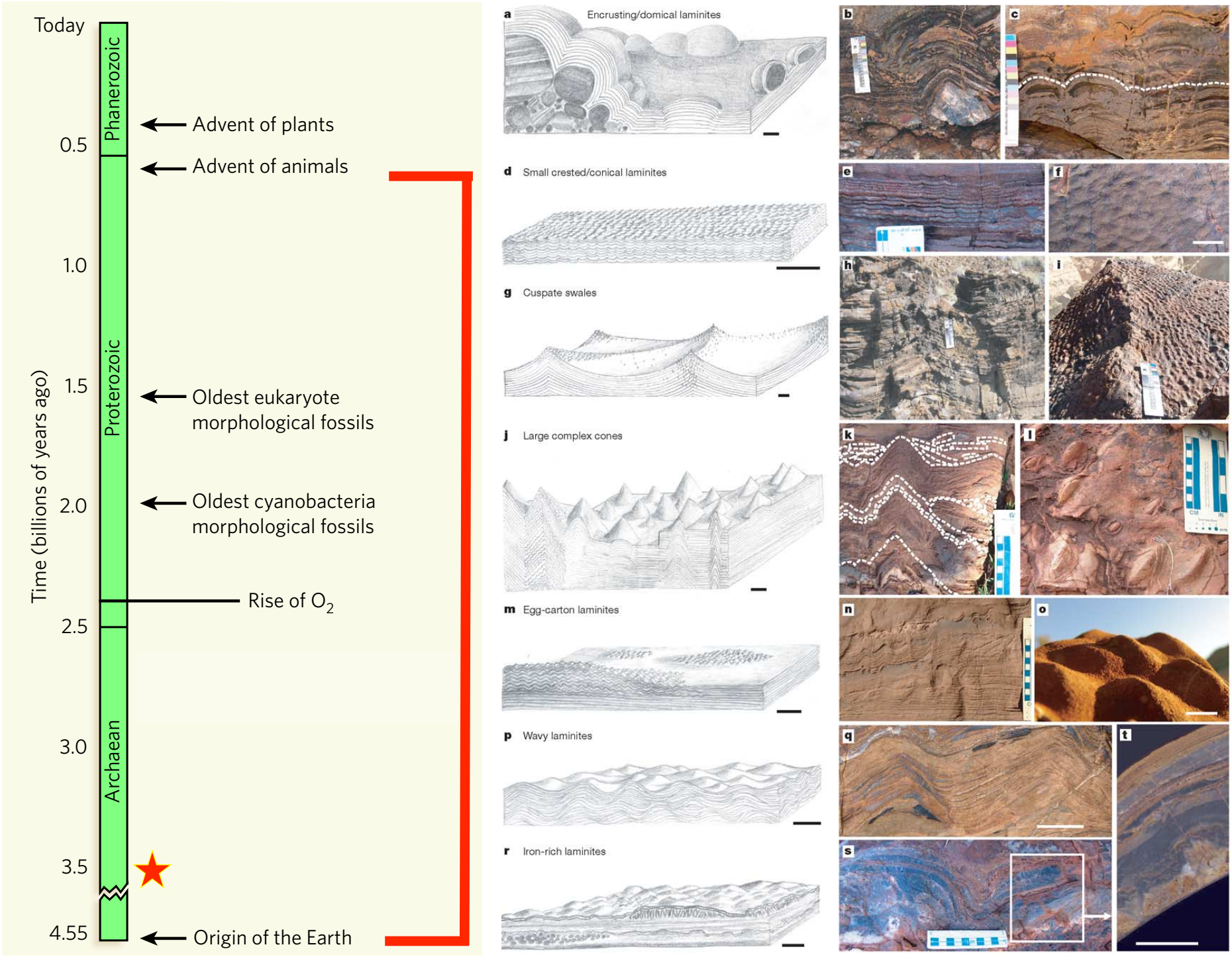
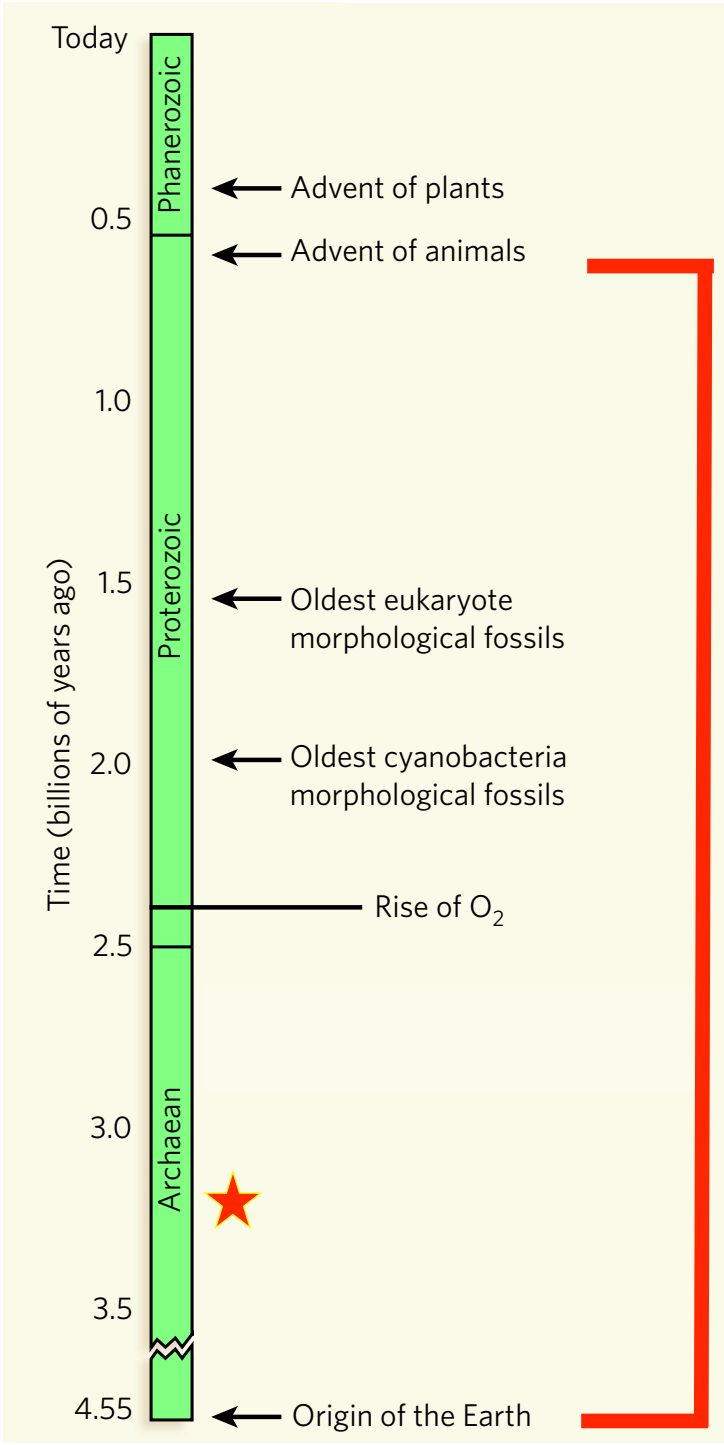
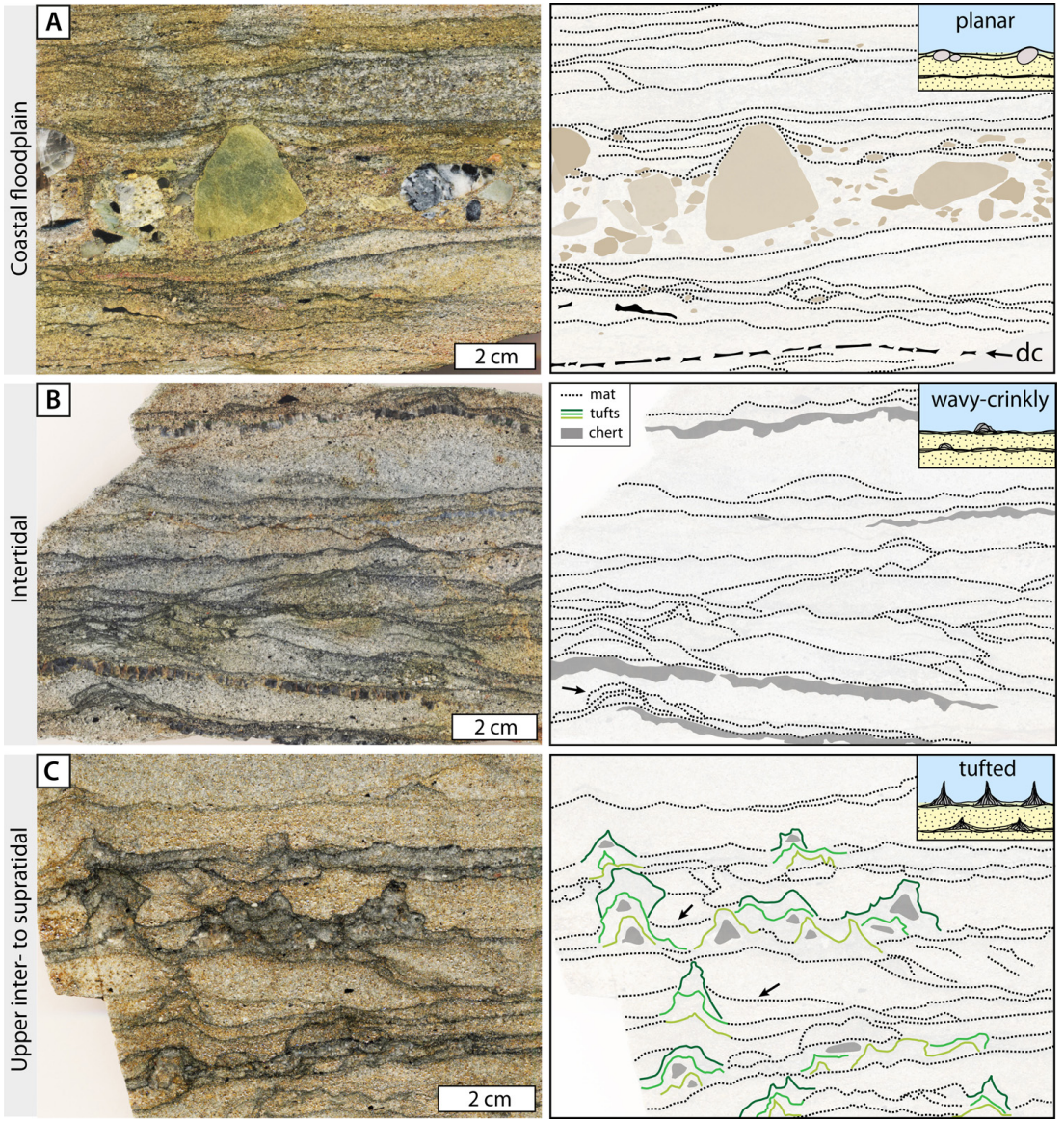
0.5
Advent of plants
Advent of animals
1.0
Proterozoic
1.5
Oldest eukaryote morphological fossils
2.0
Oldest cyanobacteria morphological fossils
Rise of O_2
2.5
Archaean
3.0
3.5
4.55
Origin of the Earth
Time (billions of years ago)

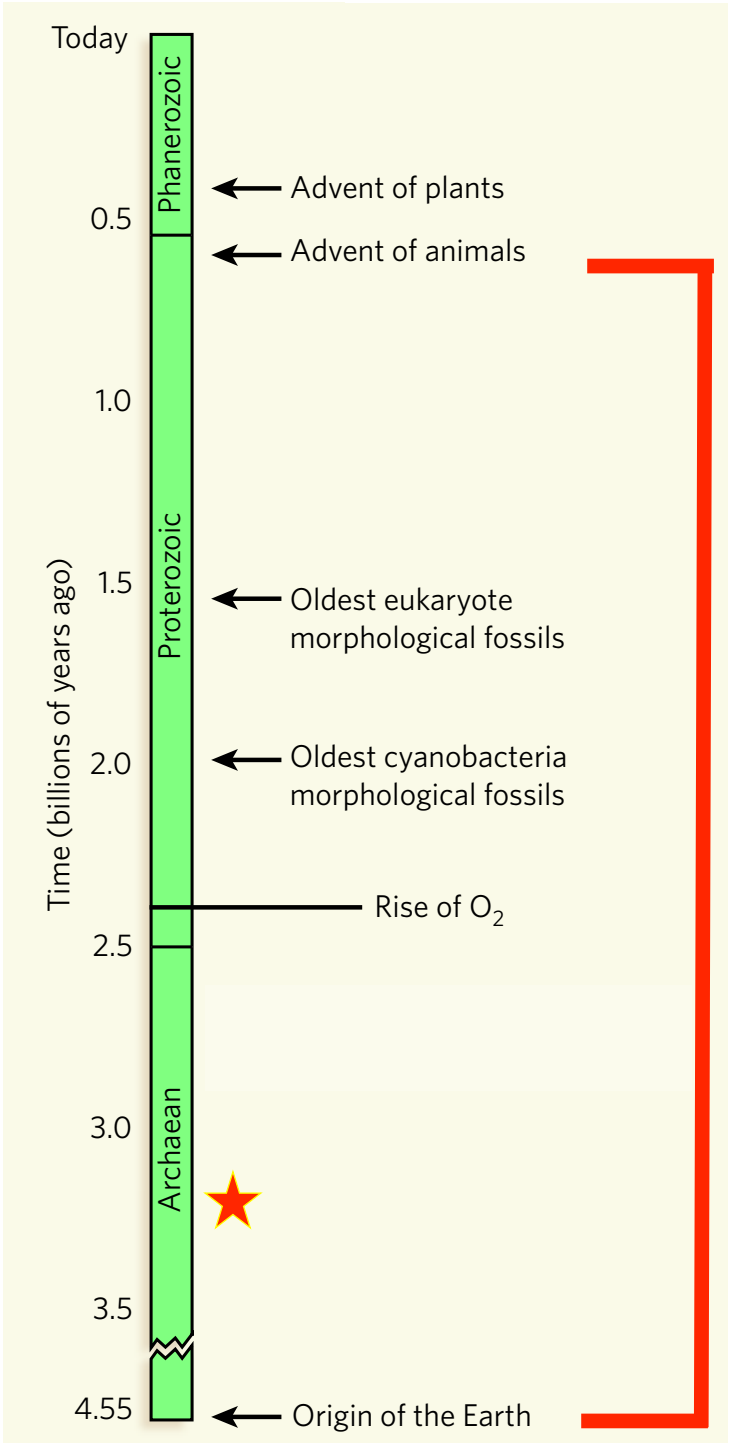

Today
Phanerozoic
Proterozoic
Archaean
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.55
Time (billions of years ago)
Advent of plants
Advent of animals
Oldest eukaryote morphological fossils
Oldest cyanobacteria morphological fossils
Rise of O_2
Origin of the Earth
a Encrusting/domical laminites
d Small crested/conical laminites
g Cuspate swales
j Large complex cones
m Egg-carton laminites
p Wavy laminites
r Iron-rich laminites
b
c
e
f
h
i
k
l
n
o
q
s
t



Morphological adaptations of 3.22 Ga-old tufted microbial mats to Archean coastal habitats (Moodies Group, Barberton Greenstone Belt, South Africa)

Martin Homann[a,*], Christoph Heubeck[b], Alessandro Airo[a], Michael M. Tice[c]





nature geoscience

ARTICLES

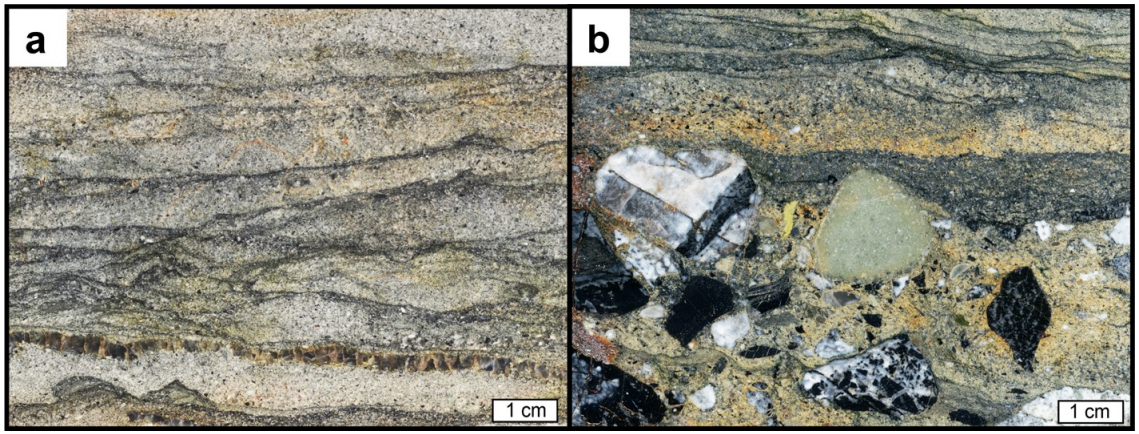
https://doi.org/10.1038/s41561-018-0190-9

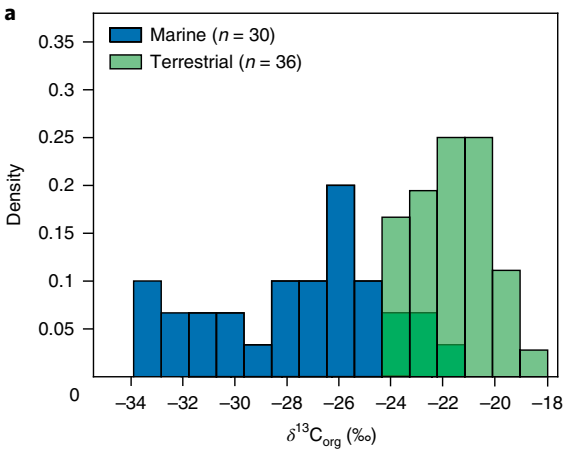
Microbial life and biogeochemical cycling on land 3,220 million years ago

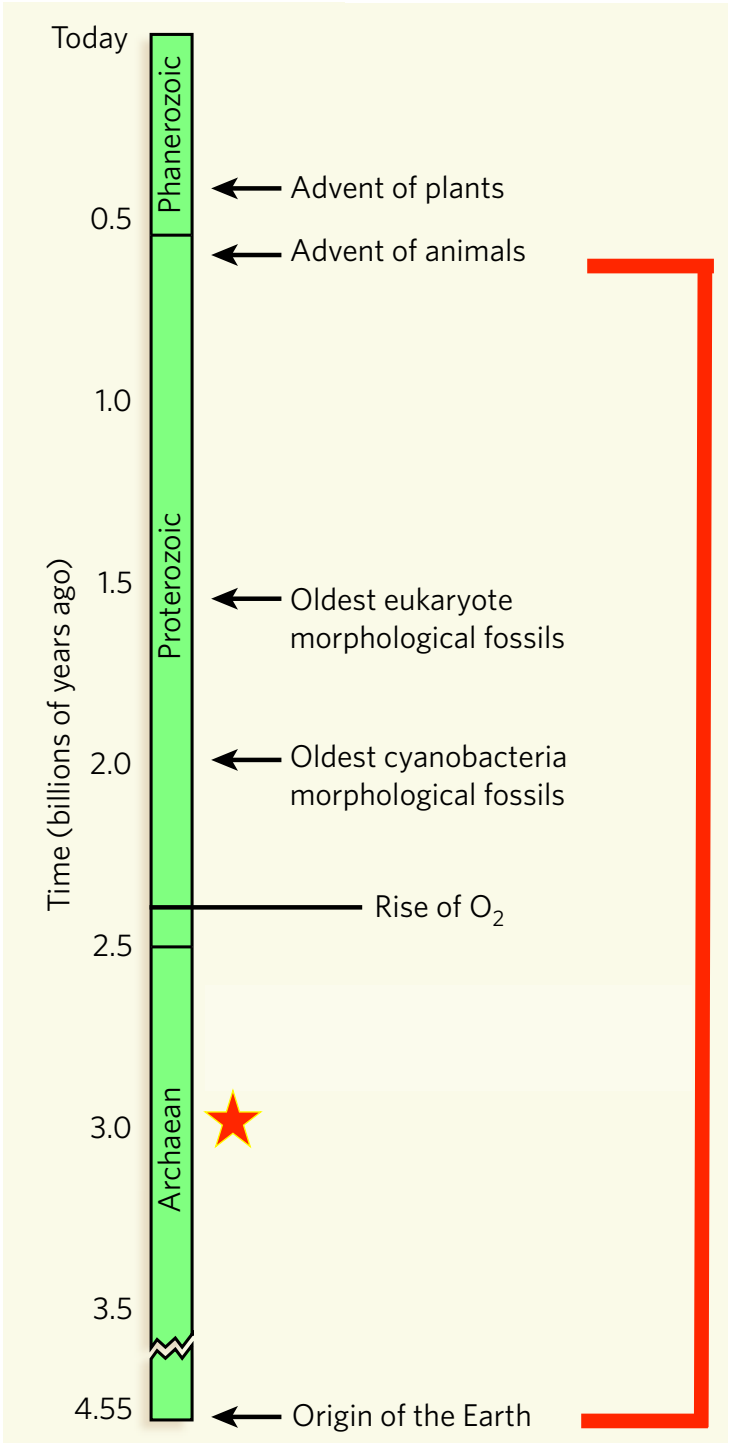
Martin Homann[1]*, Pierre Sansjofre[1], Mark Van Zuilen[2], Christoph Heubeck[3], Jian Gong[2], Bryan Killingsworth[1], Ian S. Foster[1], Alessandro Airo[4], Martin J. Van Kranendonk[5], Magali Ader[3] and Stefan V. Lalonde[1]

Tapis Microbiens Marins

Tapis Microbiens Terrestres

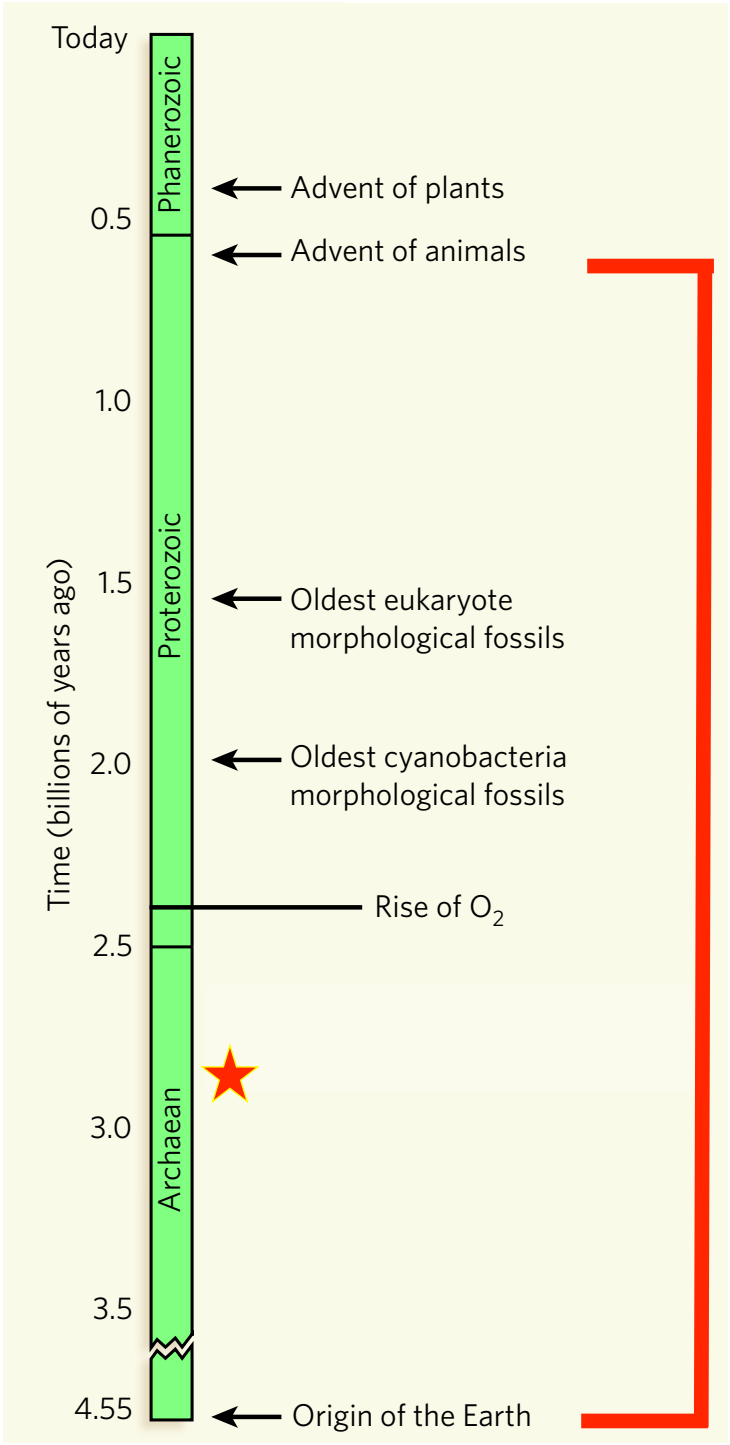






SILICICLASTIC—CARBONATE TIDAL DEPOSITS FROM THE 3000 M.Y. PONGOLA SUPERGROUP, SOUTH AFRICA

V. von BRUNN and T.R. MASON



Contents lists available at ScienceDirect

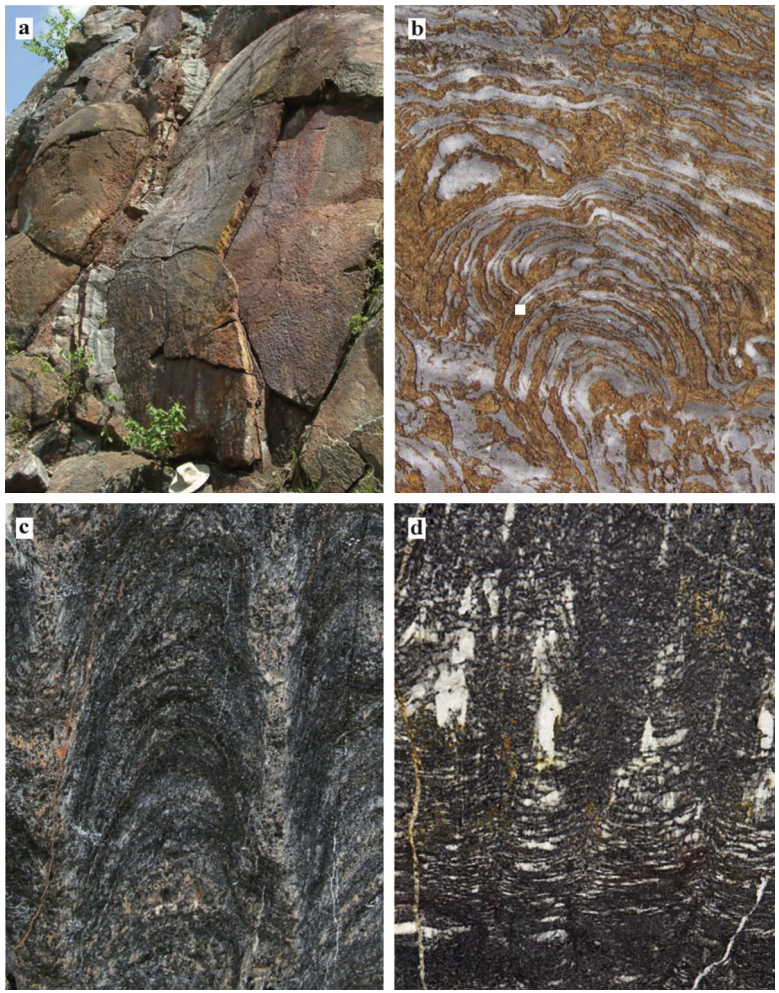
Earth-Science Reviews

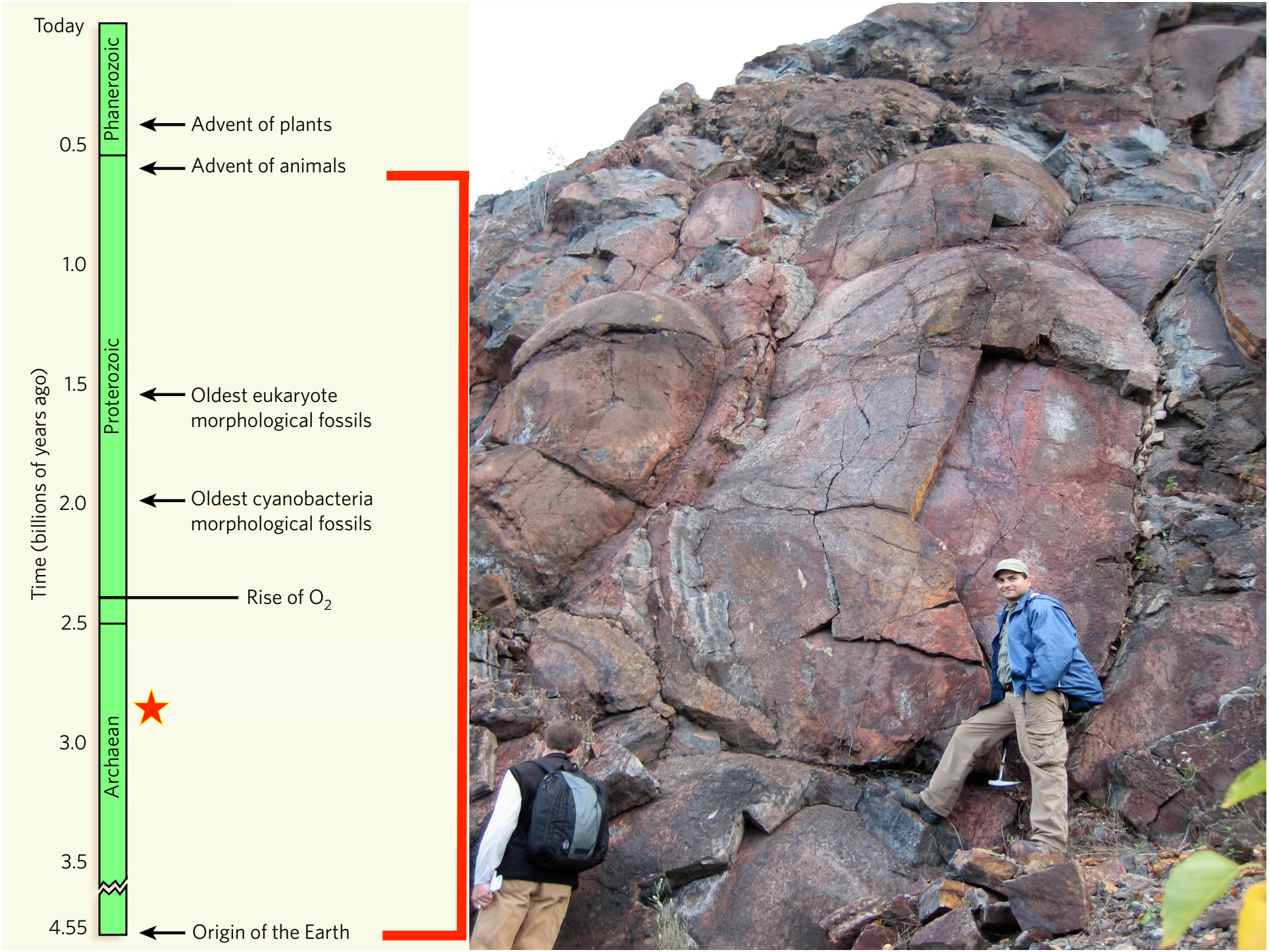
journal homepage: www.elsevier.com/locate/earscirev

Steep Rock Lake: Sedimentology and geochemistry of an Archean carbonate platform

Philip Fralick [a], Robert Riding [b]

[a] Department of Geology, Lakehead University, Thunder Bay, ON, P7B 5E1, Canada
[b] Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996, USA




Today
Phanerozoic
Proterozoic
Archaean
Time (billions of years ago)
0.5
1.0
1.5
2.0
2.5
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Advent of plants
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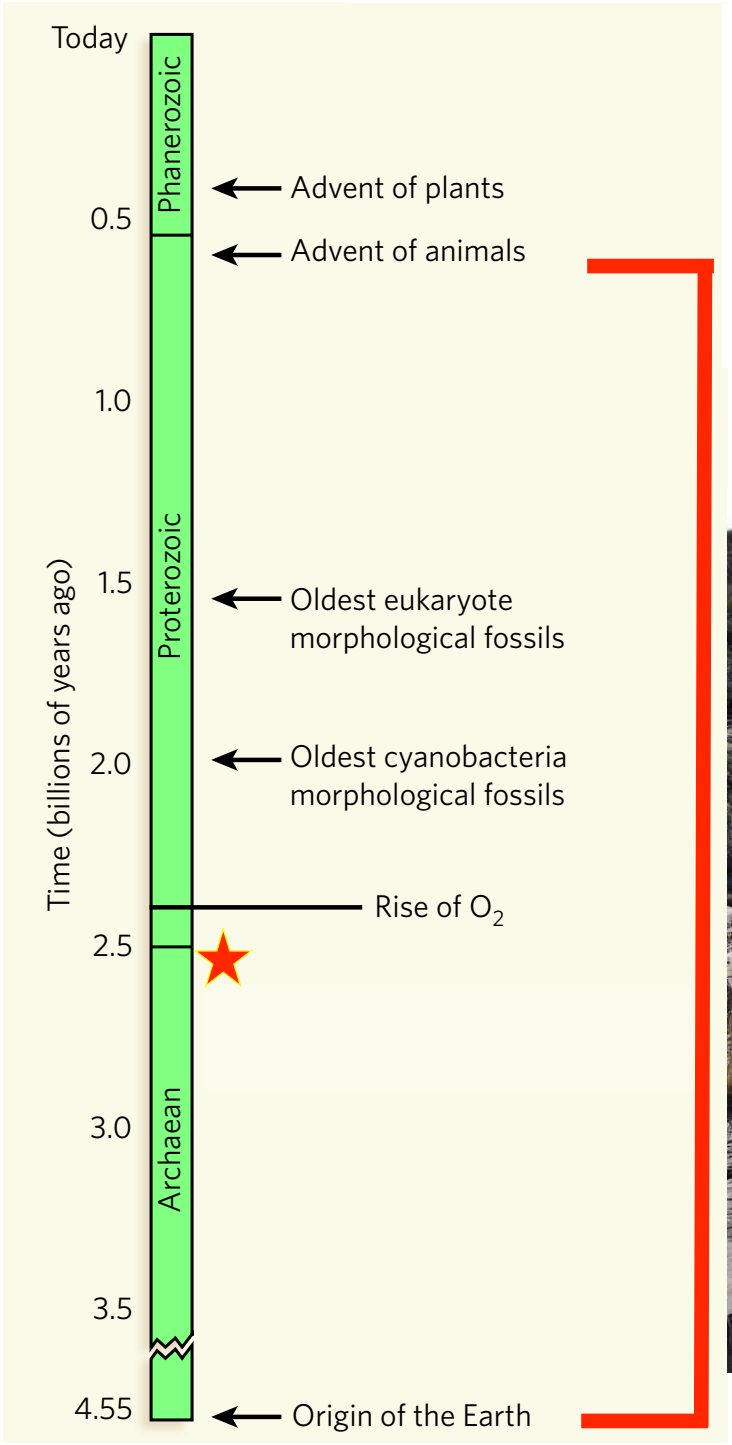


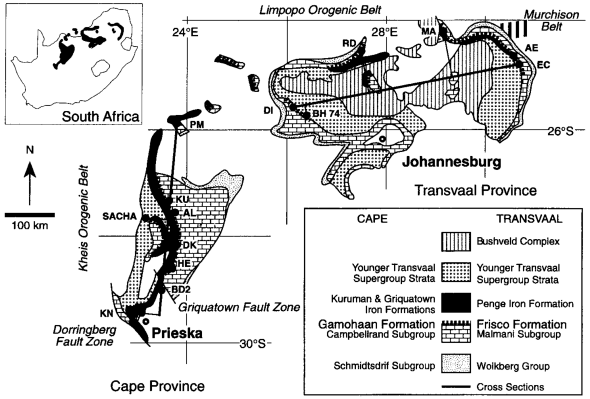
[American Journal of Science, Vol. 297, May, 1997, P. 455–487]

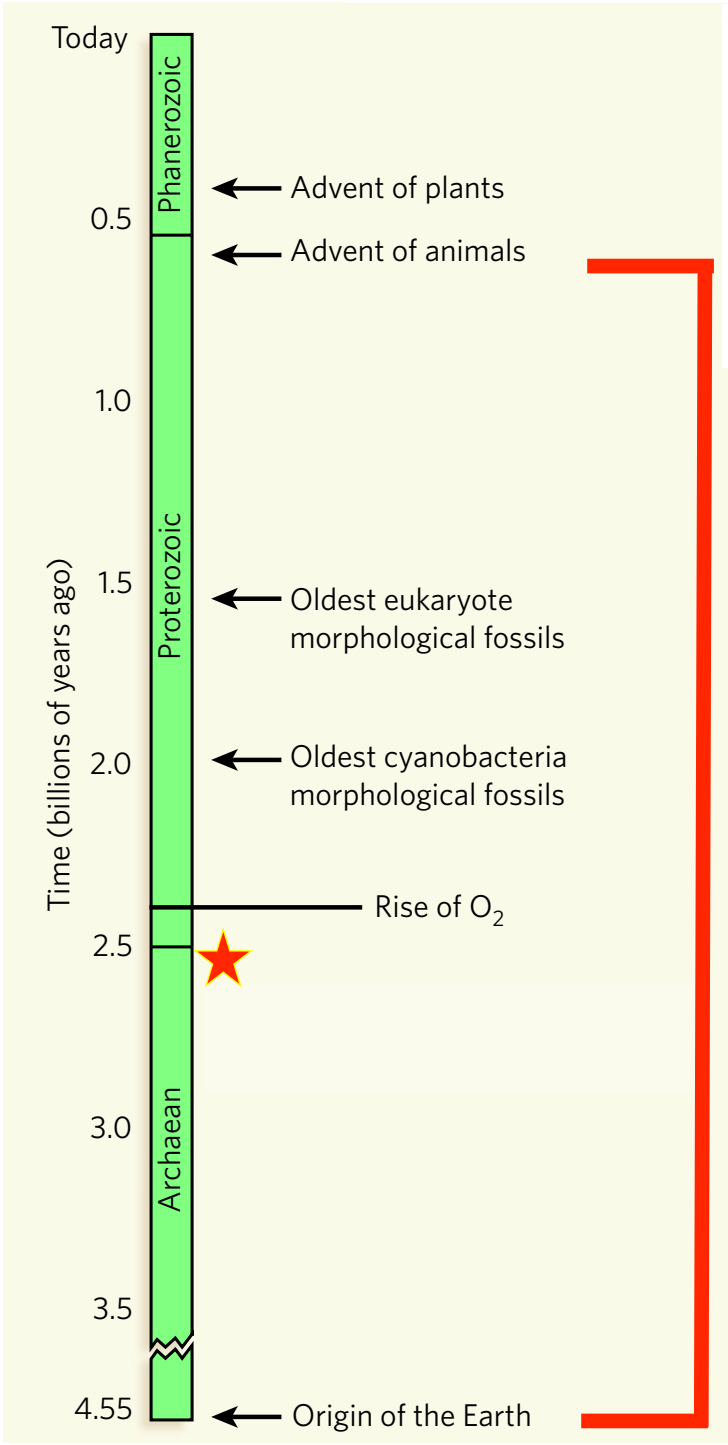
American Journal of Science

MAY 1997

CARBONATE PRECIPITATION AND OXYGEN STRATIFICATION IN LATE ARCHEAN SEAWATER AS DEDUCED FROM FACIES AND STRATIGRAPHY OF THE GAMOHAAN AND FRISCO FORMATIONS, TRANSVAAL SUPERGROUP, SOUTH AFRICA

DAWN Y. SUMNER*
Earth, Atmospheric, and Planetary Sciences,
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139





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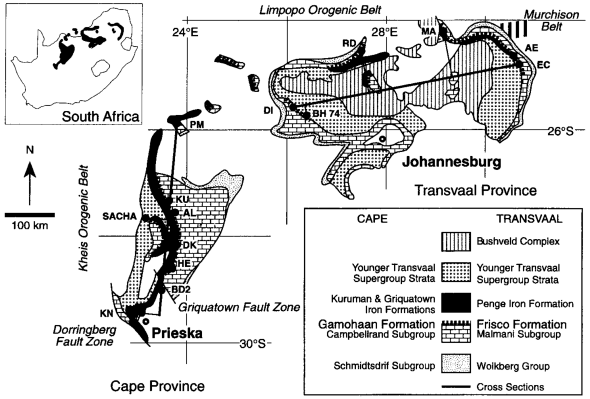

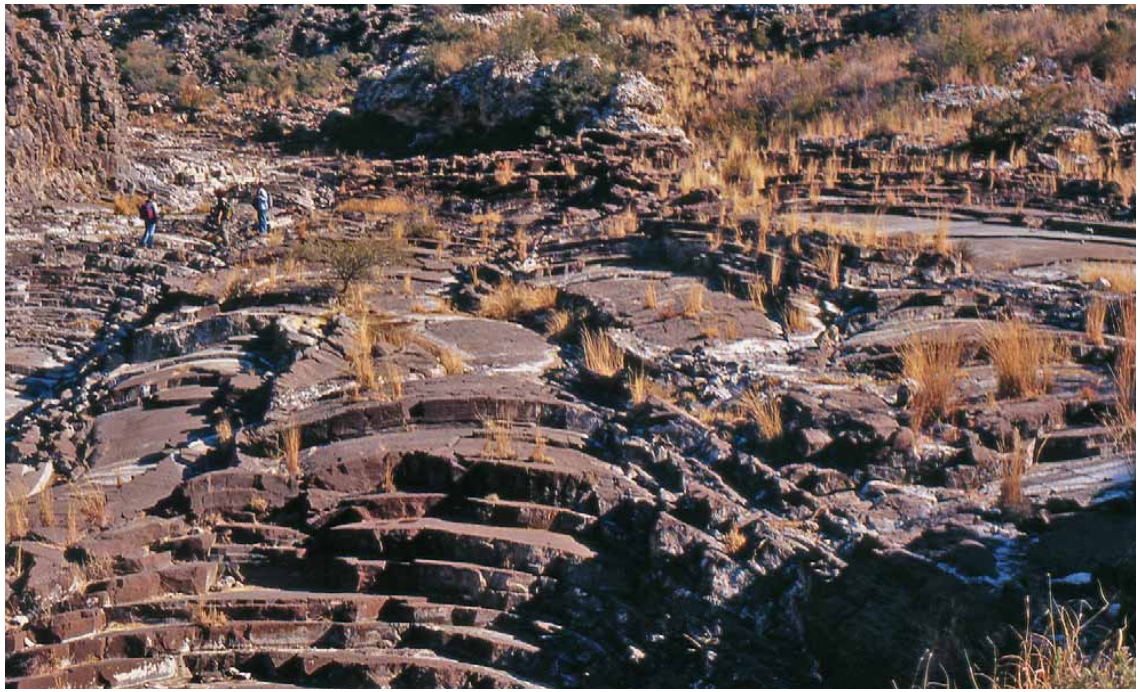

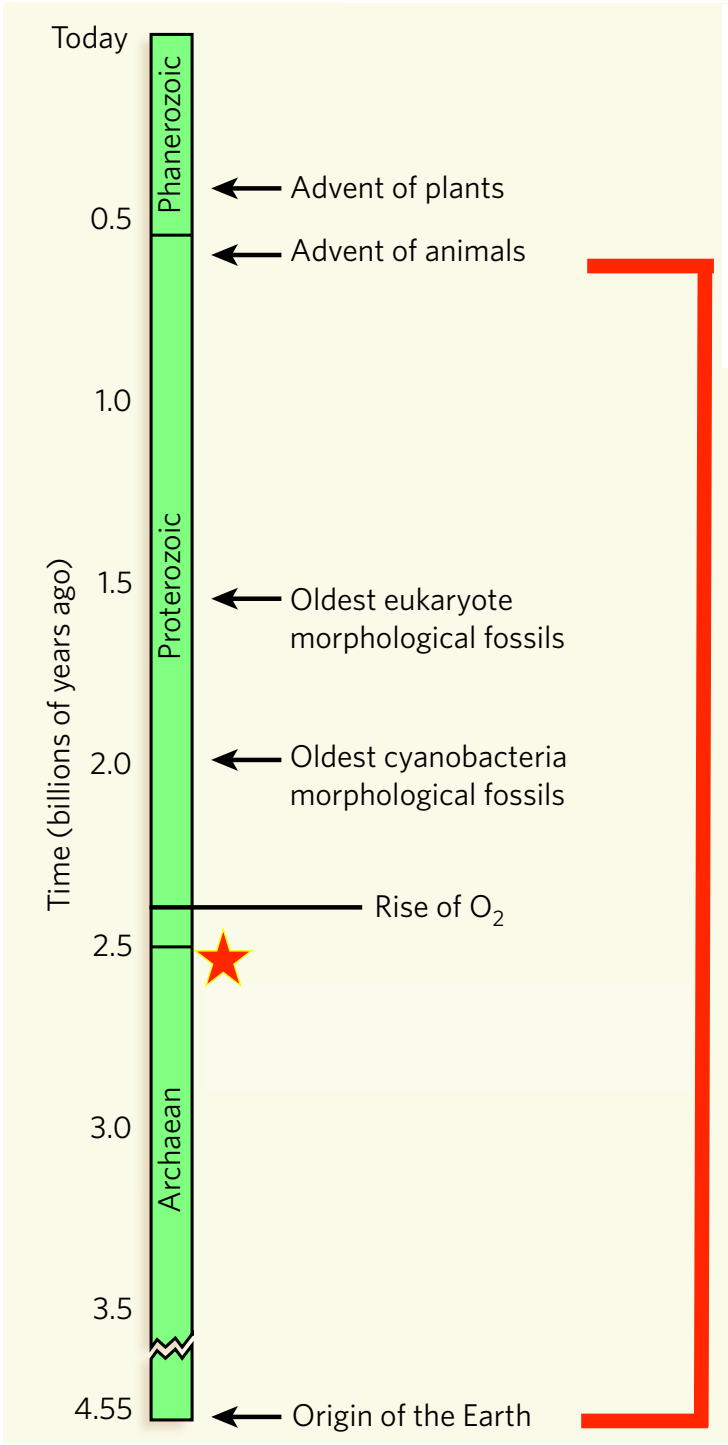

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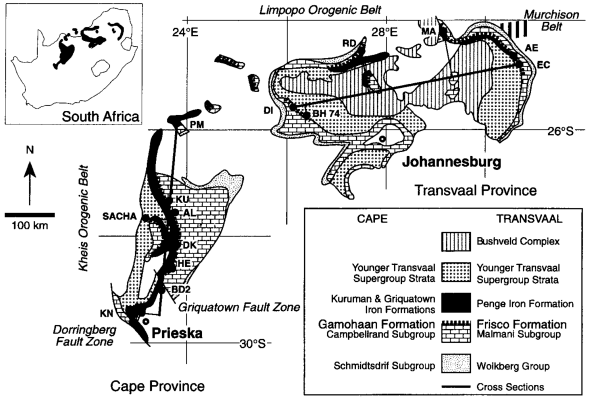

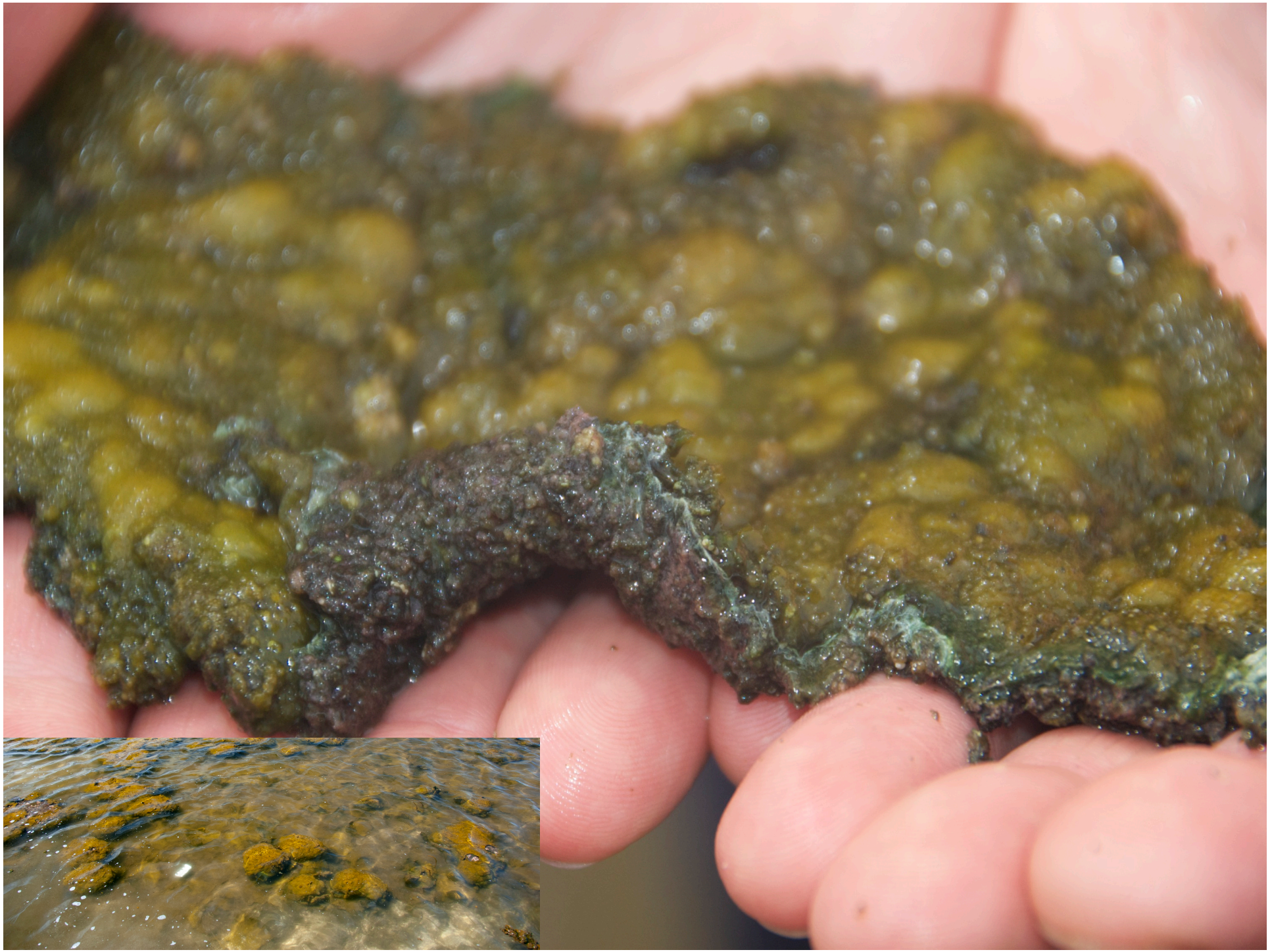

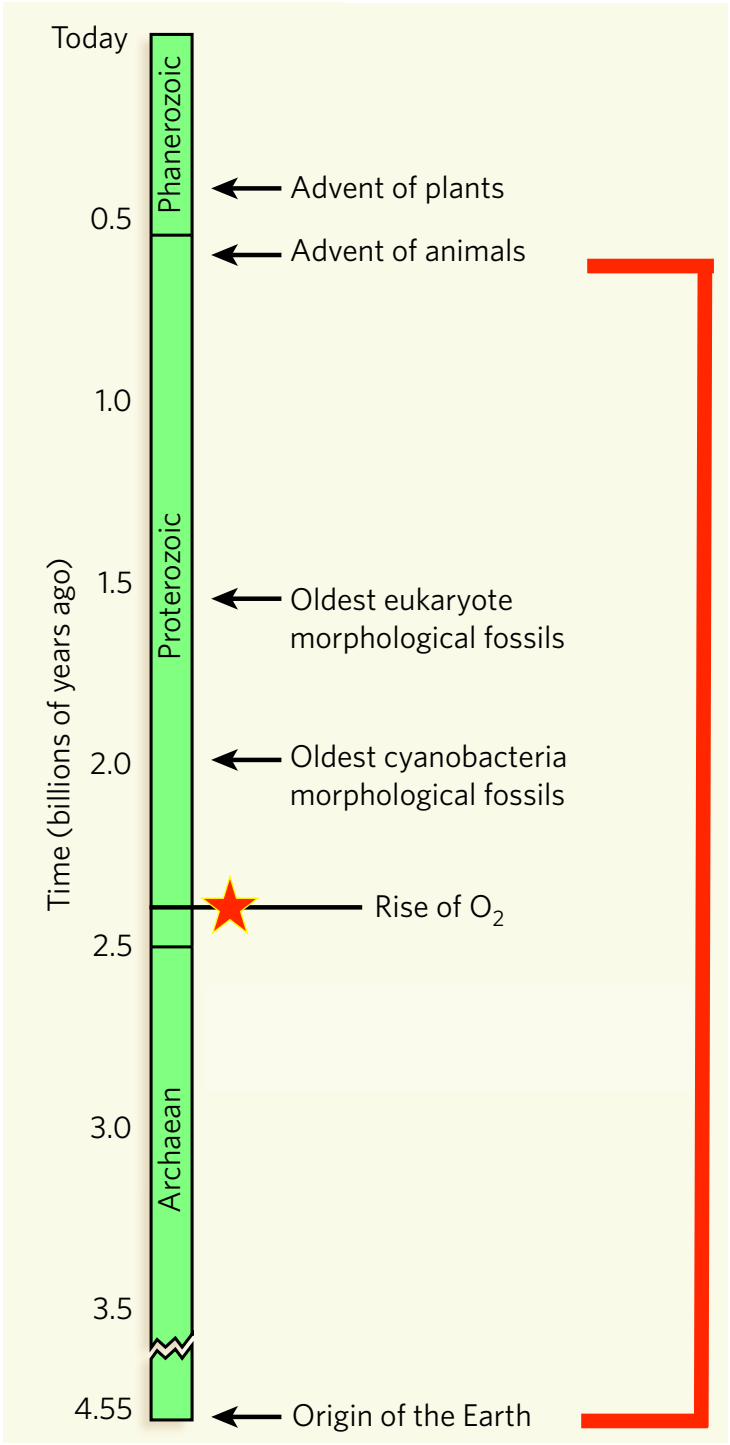
Today
Phanerozoic
Proterozoic
Archaean
0.5
1.0
1.5
2.0
2.5
3.0
3.5
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Time (billions of years ago)
Advent of plants
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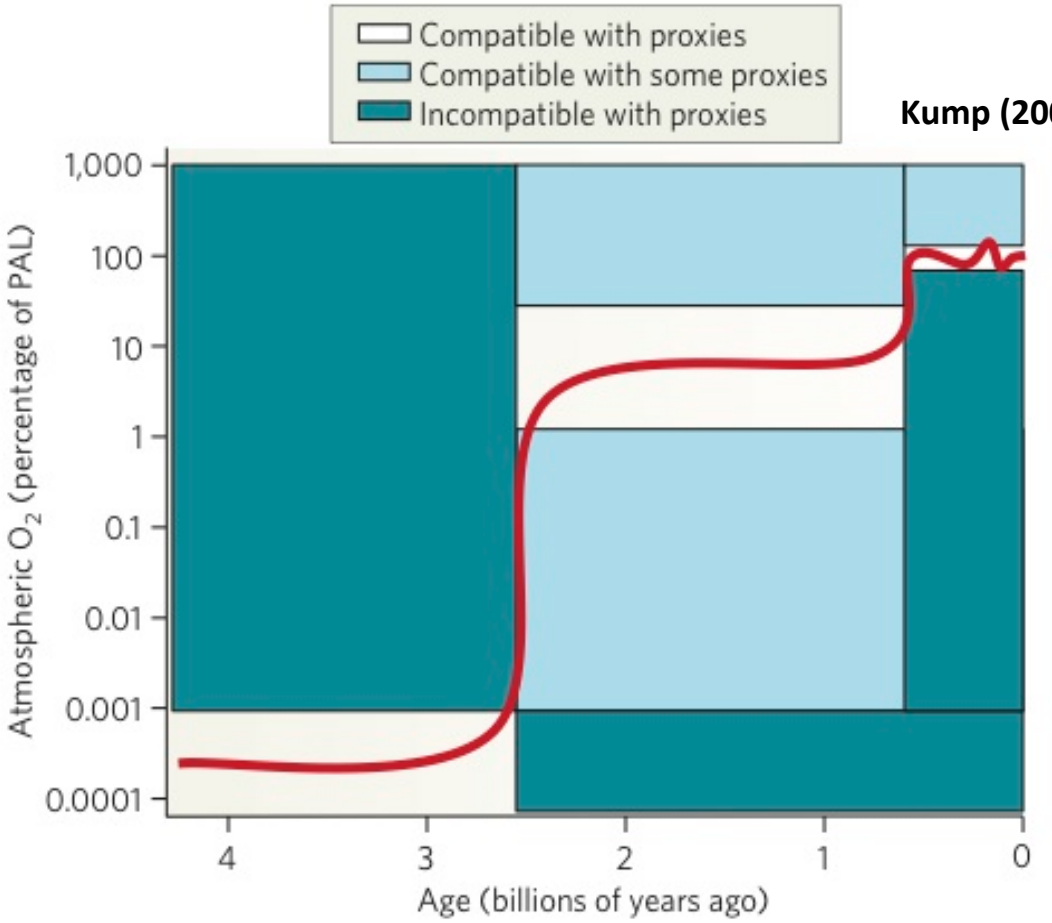
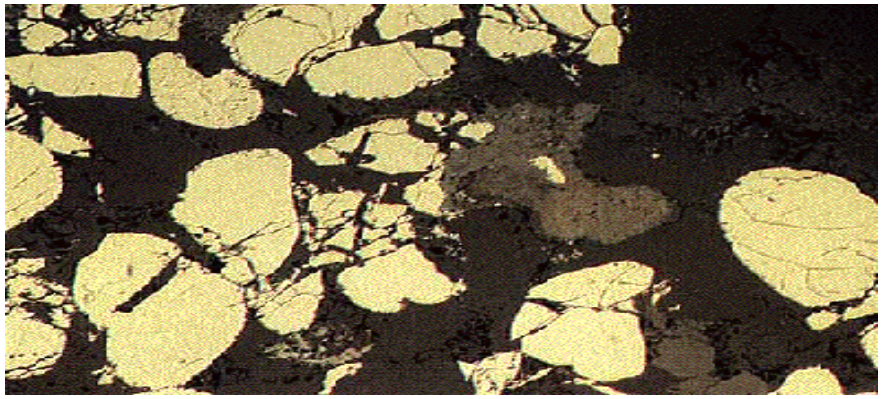
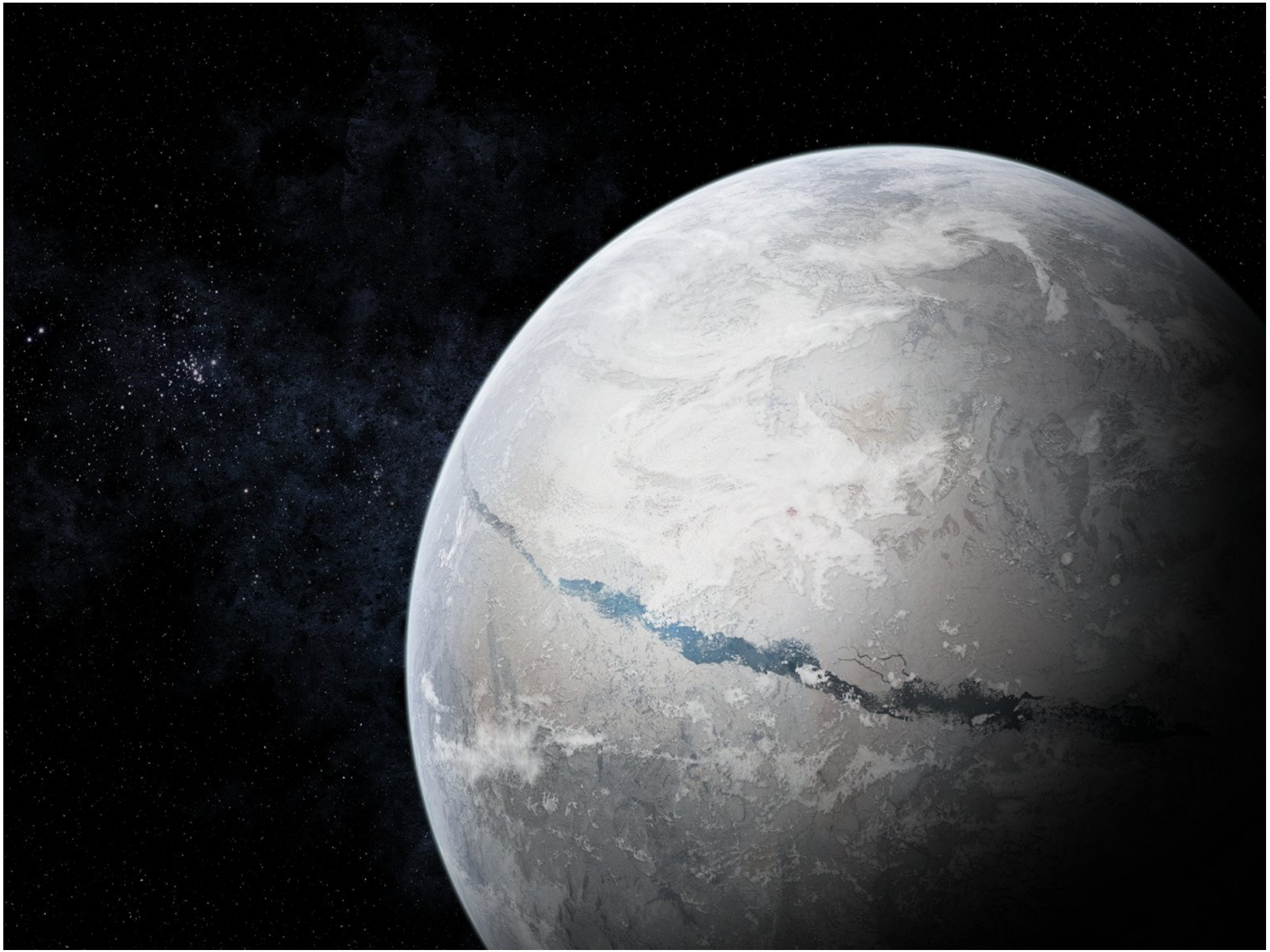
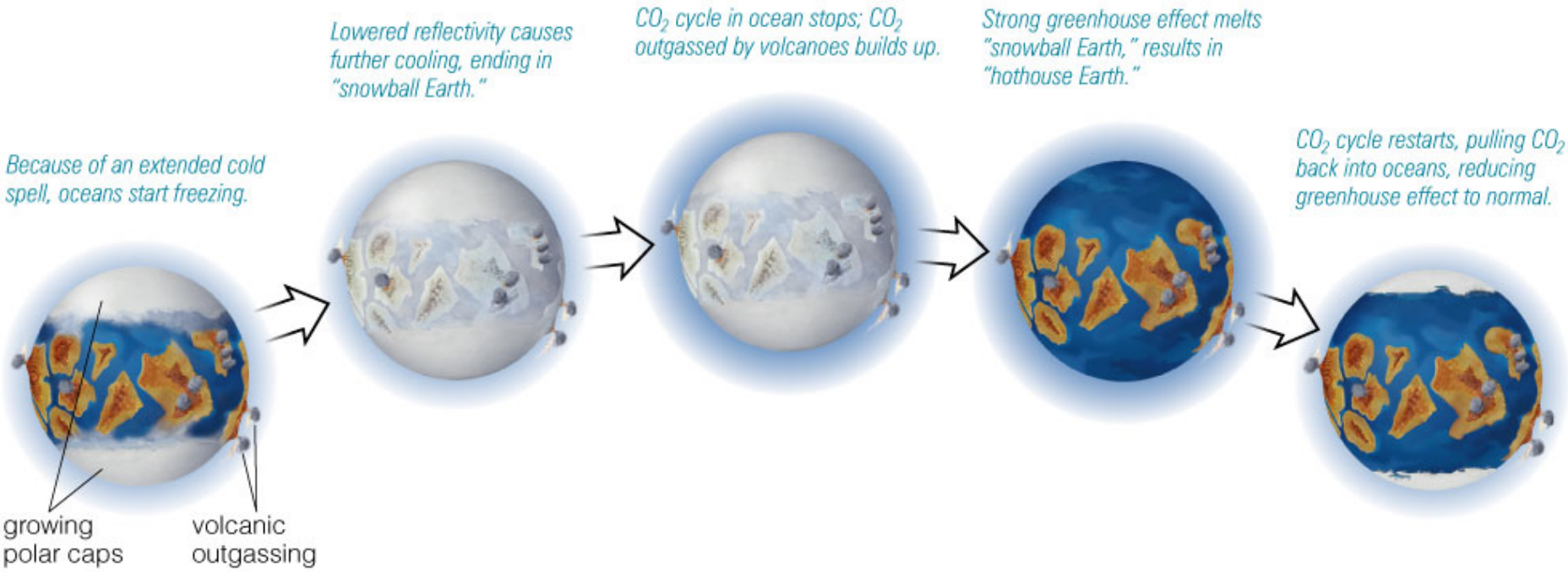
Oldest eukaryote morphological fossils
Oldest cyanobacteria morphological fossils
Rise of O_2
Origin of the Earth


Compatible with proxies
Compatible with some proxies
Incompatible with proxies
Atmospheric O_2 (percentage of PAL)
1,000
100
10
1
0.1
0.01
0.001
0.0001
4
3
2
1
0
Age (billions of years ago)

Kump (2008)







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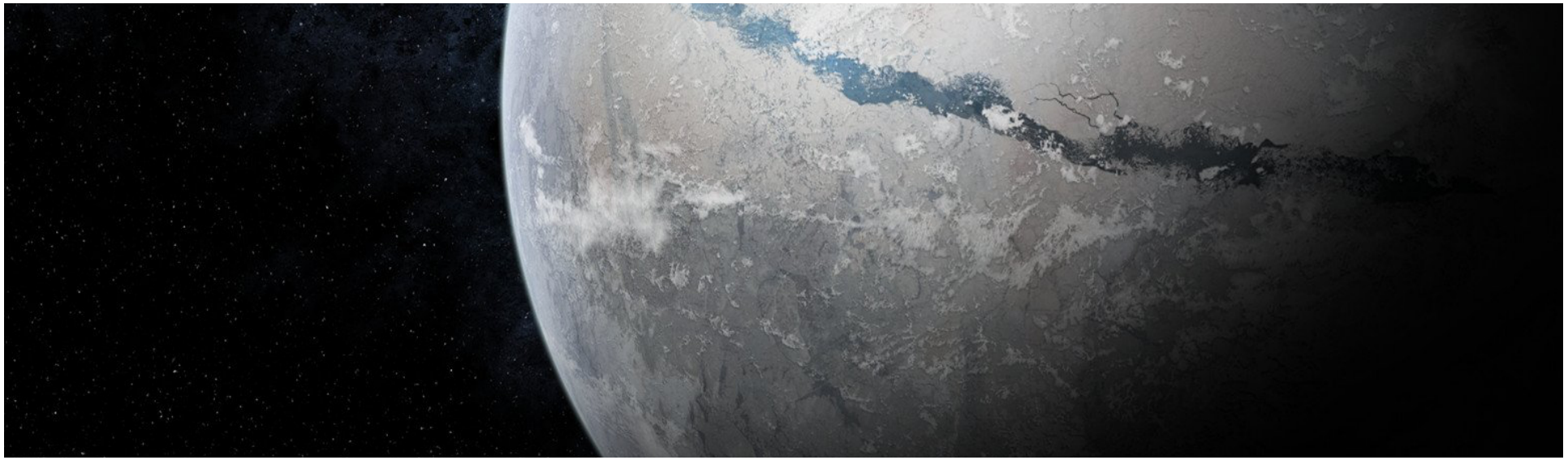

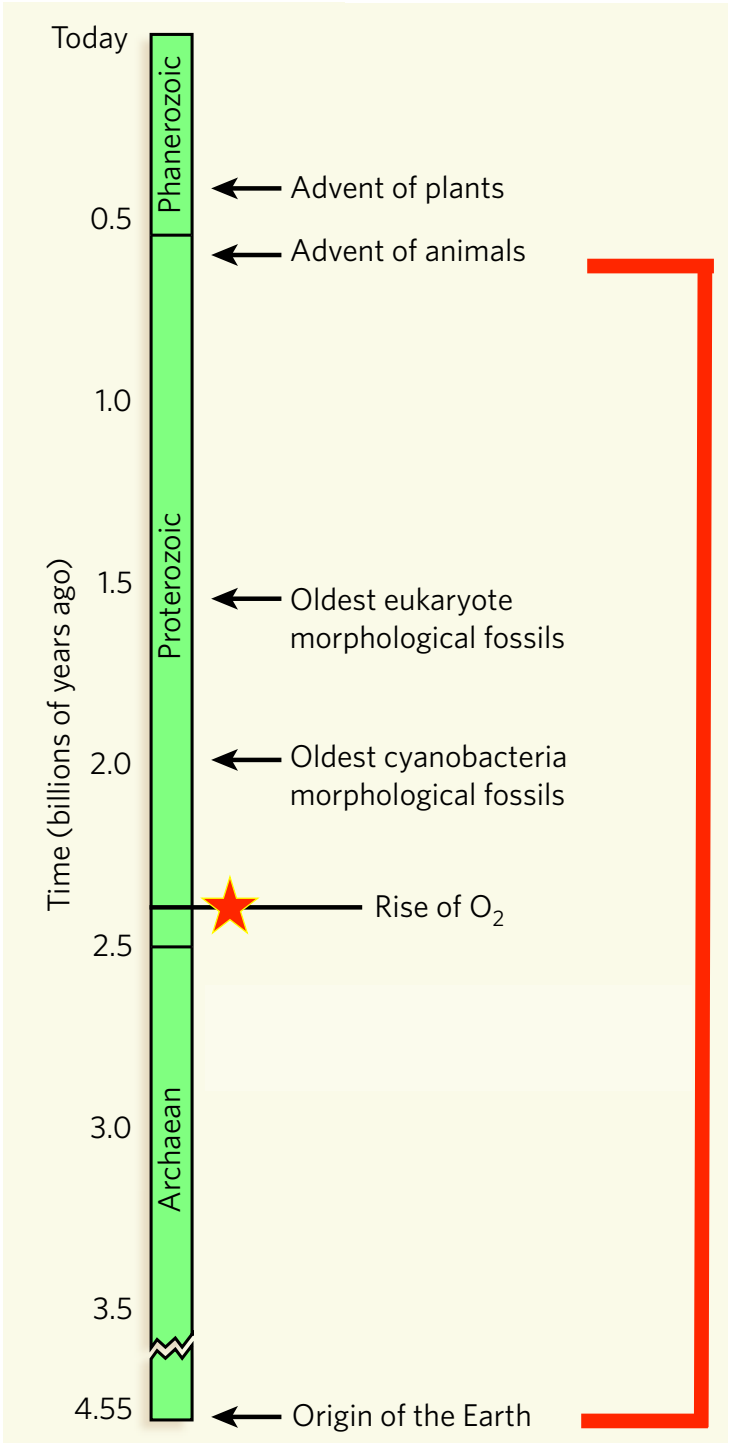
Today
Phanerozoic
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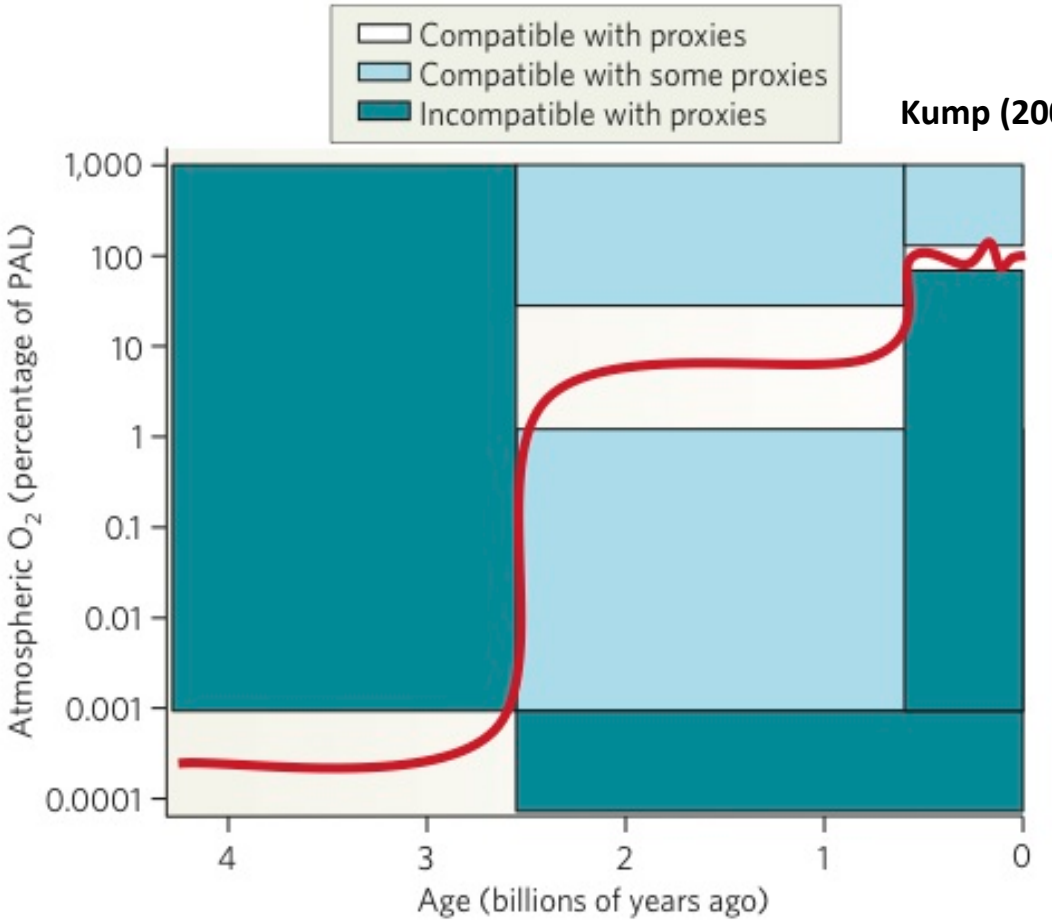
Compatible with proxies
Compatible with some proxies
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100
10
1
0.1
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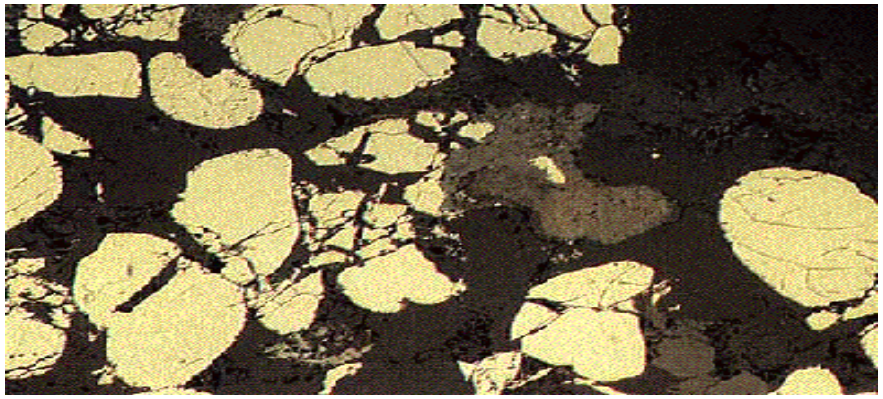
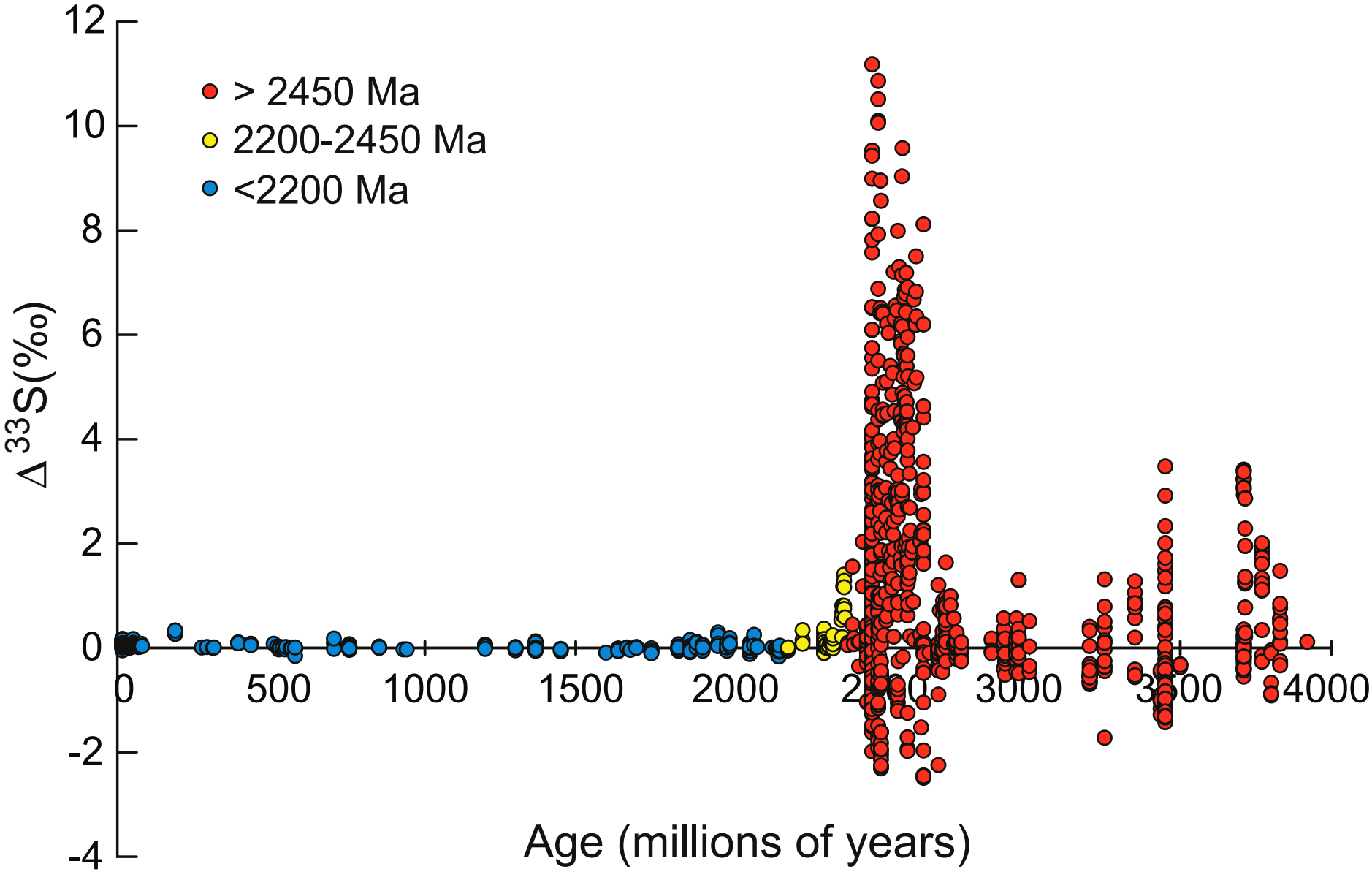
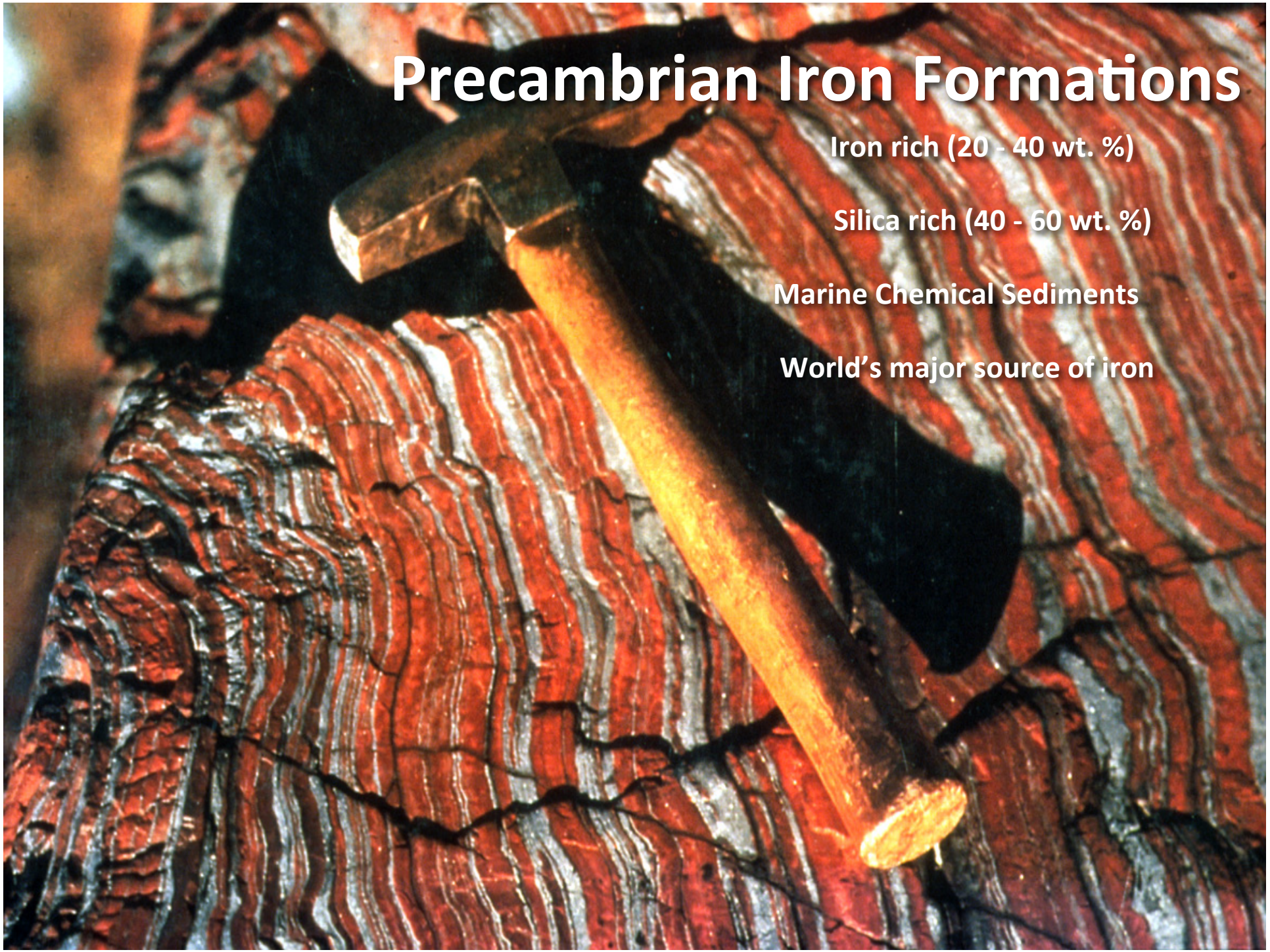


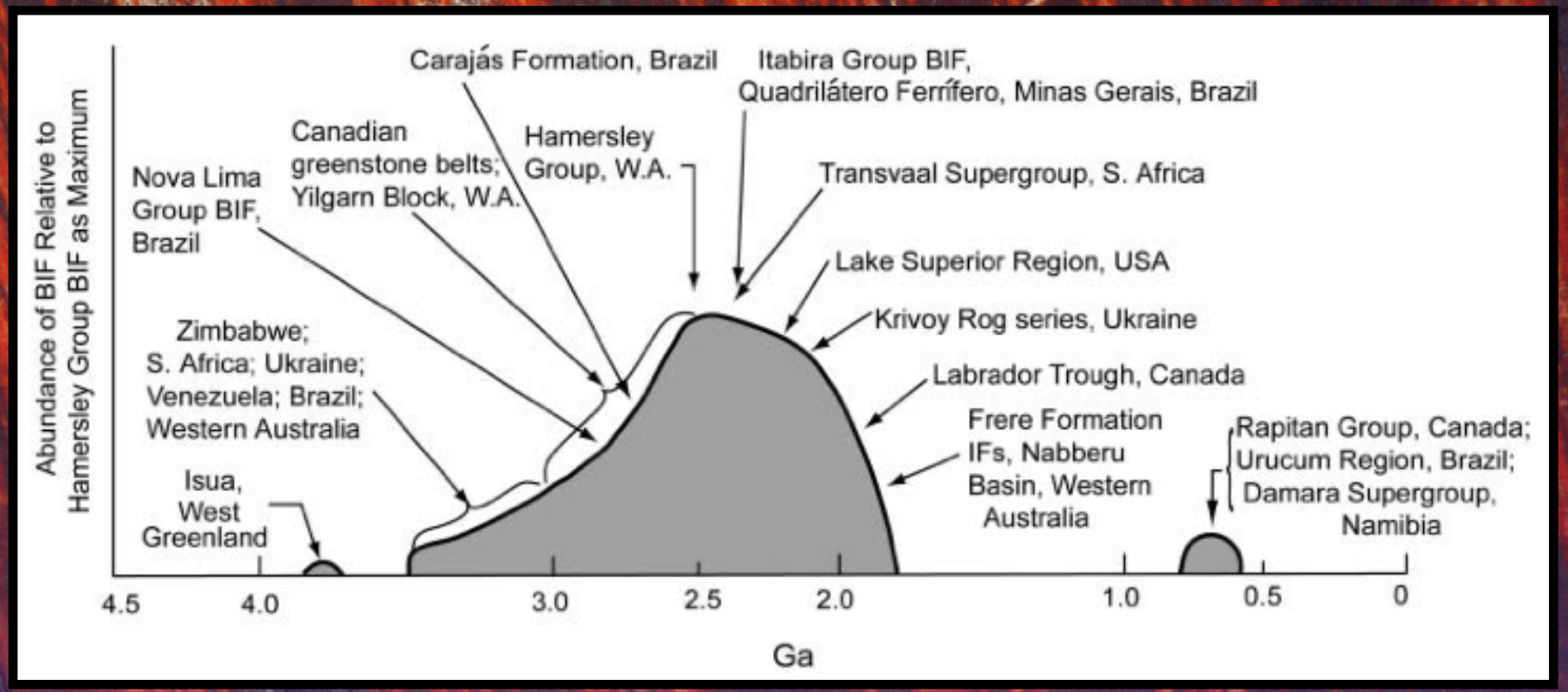


Lowenstein, Kendall, and Anbar (Treatise on Geochemistry, 2014)

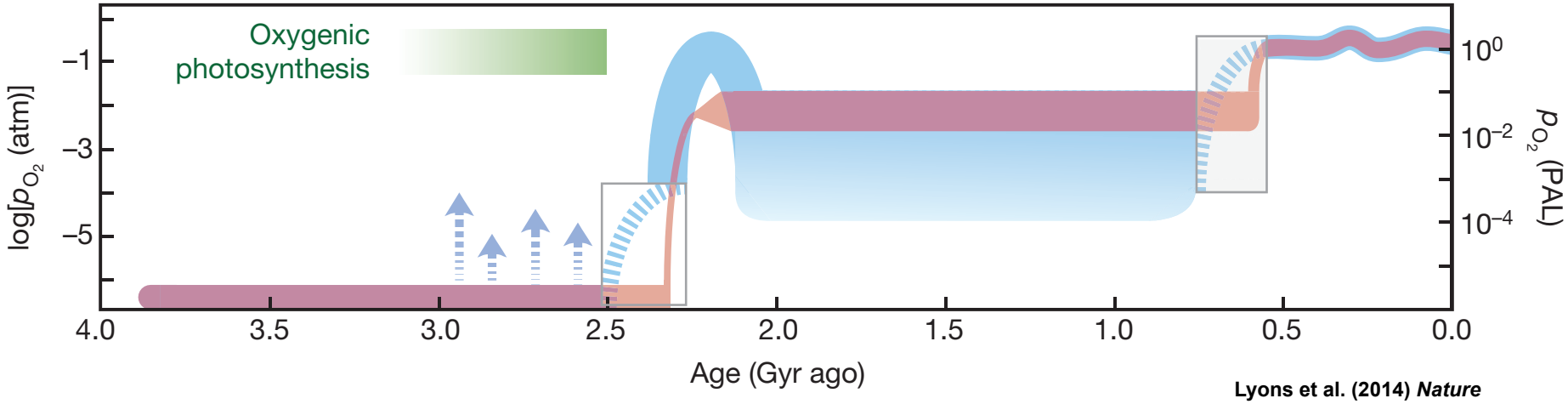

Precambrian Iron Formations
Iron rich (20 - 40 wt. %)
Silica rich (40 - 60 wt. %)
Marine Chemical Sediments
World's major source of iron

Globally Distributed

Exclusively Precambrian

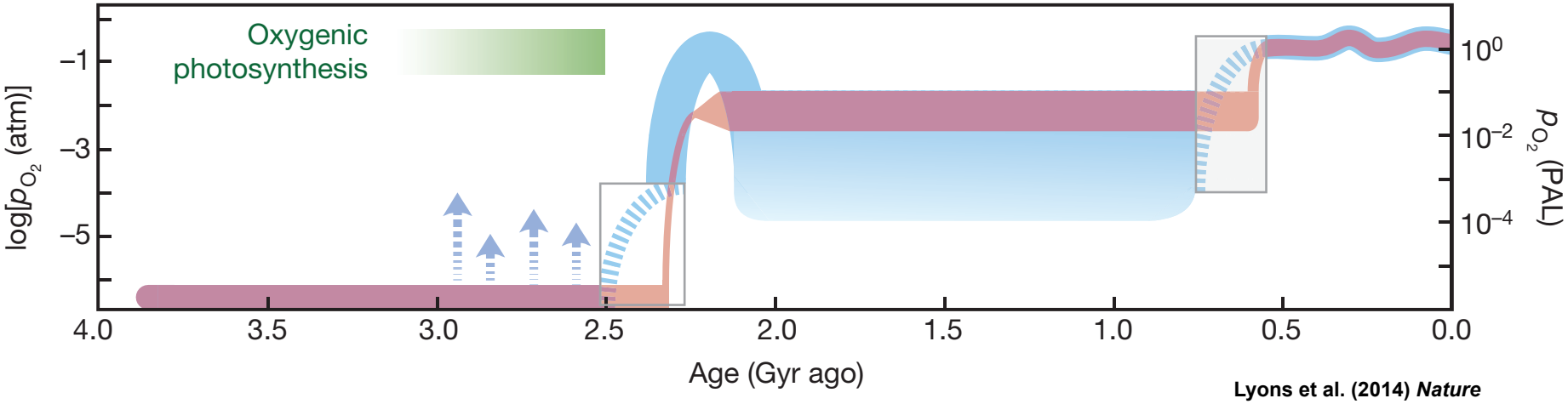


Klein, C. (2005) *American Mineralogist* 90:1473



Lyons et al. (2014) ***Nature***

Les origines de la photosynthèse oxygénique ne sont pas très claires…



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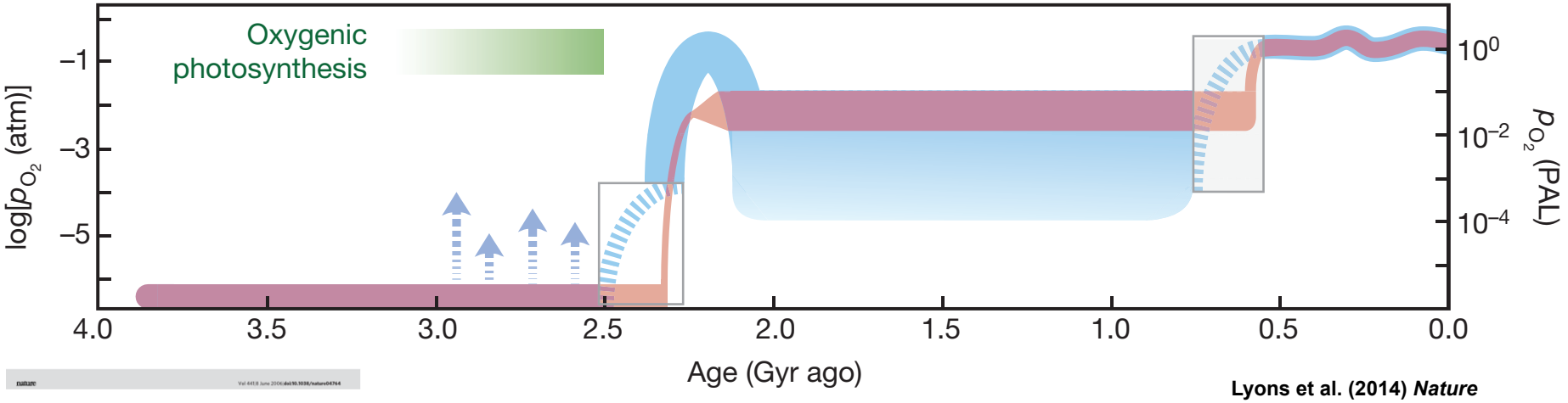

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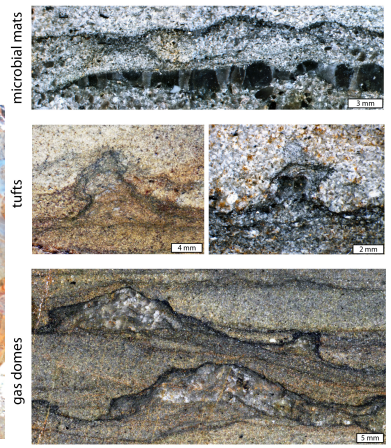

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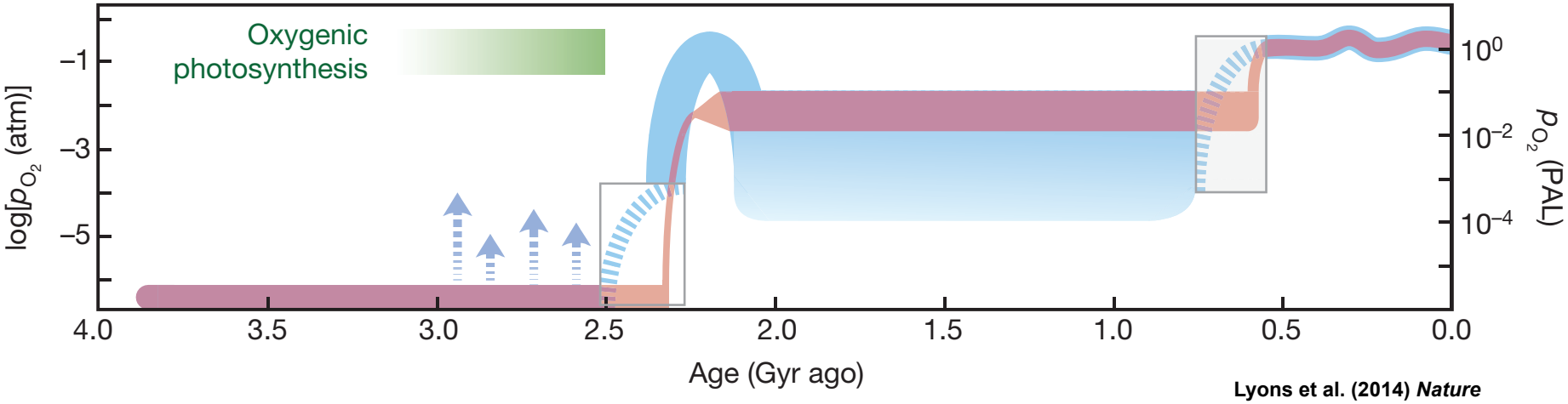
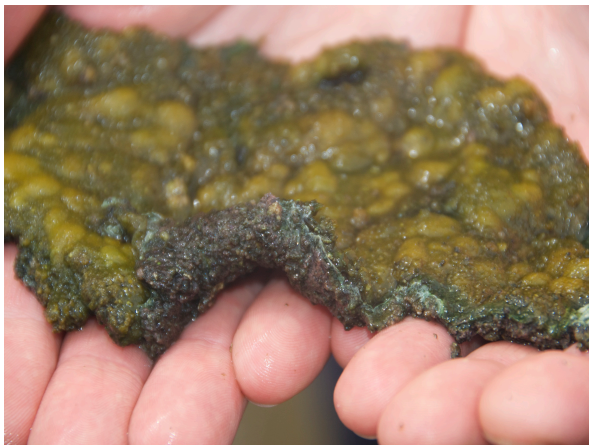


Lyons et al. (2014) ***Nature***

Anoxygénique

vs.

Oxygénique



De nombreuses études suggèrent la présence d'oasis d'oxygène avant le GOE:

Science
AAAS

A Whiff of Oxygen Before the Great Oxidation Event?

Ariel D. Anbar, *et al.*

Science **317**, 1903 (2007);
DOI: 10.1126/science.1140325

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SciVerse ScienceDirect

Geochimica et Cosmochimica Acta 86 (2012) 118–137

Geochimica et Cosmochimica Acta

www.elsevier.com/locate/gca

Evidence for free oxygen in the Neoarchean ocean based on coupled iron–molybdenum isotope fractionation

Andrew D. Czaja [a,b,*], Clark M. Johnson [a,b], Eric E. Roden [a,b], Brian L. Beard [a,b], Andrea R. Voegelin [c], Thomas F. Nägler [c], Nicolas J. Beukes [d], Martin Wille [e]

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Atmospheric sulfur rearrangement 2.7 billion years ago: Evidence for oxygenic photosynthesis

Florian Kurzweil [a,b,*], Mark Claire [c], Christophe Thomazo [d], Marc Peters [e], Mark Hannington [f], Harald Strauss [a]

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Short communication

Identification of an Archean marine oxygen oasis

Robert Riding [a,*], Philip Fralick [b], Liyuan Liang [c]

GEOLOGY

Oxygenation of the Archean atmosphere: New paleosol constraints from eastern India

Joydip Mukhopadhyay[1], Quentin G. Crowley[2]*, Sampa Ghosh[1], Gautam Ghosh[1], Kalyan Chakrabarti[1,3], Brundaban Misra[1,3], Kyle Heron[2], and Sankar Bose[1]

nature geoscience

LETTERS

PUBLISHED ONLINE: 23 MARCH 2014 | DOI: 10.1038/NGEO2122

Evidence for oxygenic photosynthesis half a billion years before the Great Oxidation Event

Noah J. Planavsky[1]*, Dan Asael[2], Axel Hofmann[3], Christopher T. Reinhard[4], Stefan V. Lalonde[5], Andrew Knudsen[6], Xiangli Wang[1,7], Frantz Ossa Ossa[3], Ernesto Pecoits[8], Albertus J. B. Smith[3], Nicolas J. Beukes[3], Andrey Bekker[9], Thomas M. Johnson[7], Kurt O. Konhauser[8], Timothy W. Lyons[9] and Olivier J. Rouxel[2]

LETTER

doi:10.1038/nature12426

Atmospheric oxygenation three billion years ago

Sean A. Crowe[1]†*, Lasse N. Døssing[1,2]*, Nicolas J. Beukes[3], Michael Bau[4], Stephanus J. Kruger[3], Robert Frei[2] & Donald E. Canfield[1]

Archean "whiffs of oxygen" go Poof!

JOSEPH L. KIRSCHVINK[1,*], TIMOTHY D. RAUB[2], & WOODWARD FISCHER[1]

[1] Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California, USA.

[2] Department of Earth Sciences, University of St. Andrews, St. Andrews, United Kingdom.

.... significant open-system, post-depositional alteration of the sedimentary rocks in this region of the Hamersley Basin....

....widespread highly-crystalline, high-temperature, late-stage chlorite veins, preferentially developed within shale lithologies and concentrated in the "whiff" interval...

EARLY EARTH

Cyanobacteria at work

Oxygen-producing photosynthesis must have evolved before the pervasive oxidation of the atmosp 2.4 billion years ago, but how long before is unclear. Geochemical analyses of ancient sedimentary suggest that cyanobacteria generated oxygen at least 3 billion years ago.

... The analysis is further complicated by the presence of a thick, intrusive igneous sill within metres of the Sinqeni beds that were studied from a drill core...

... additional samples that were collected from a weathered outcrop further away...

... could equally be that the sedimentary geochemistry reflects the different forms of alteration experienced by the core and outcrop rather than any primary feature...

... It is also unclear whether manganese oxides must indicate the presence of free oxygen....

European Research Council

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Earth's first biological bloom:

An integrated field, geochemical, and geobiological examination of the origins of photosynthesis and carbonate production 3 billion years ago

EARTHBLOOM Objectives

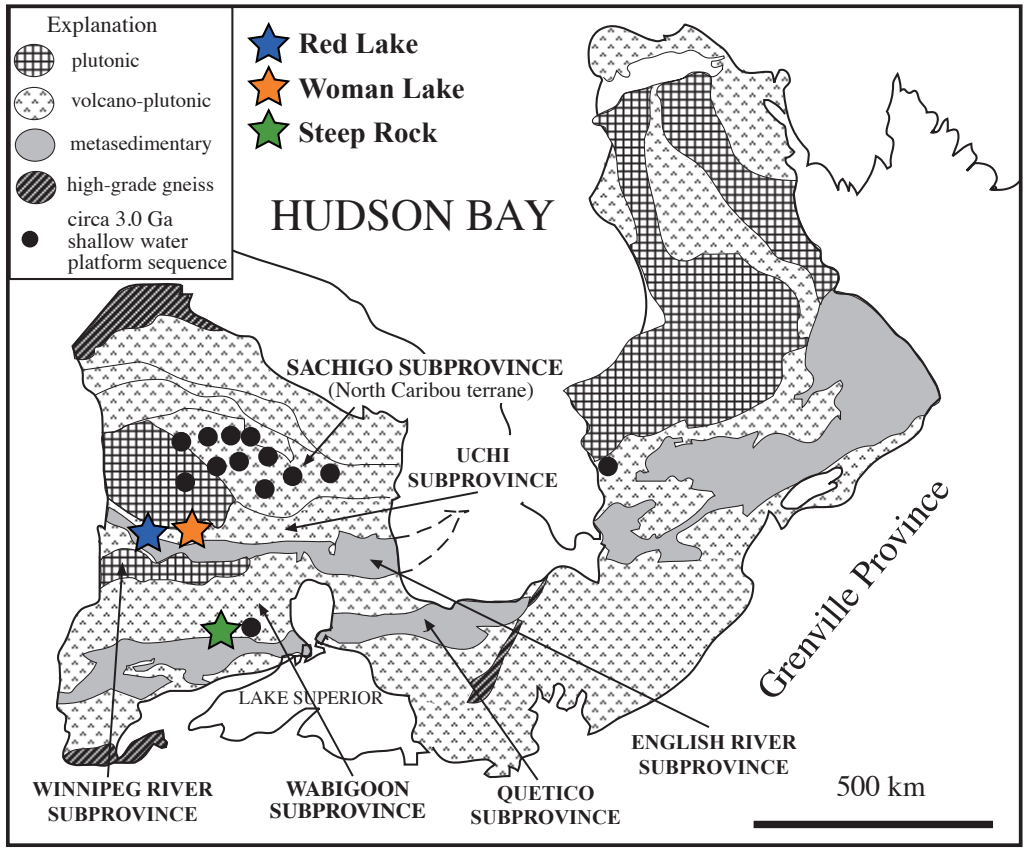
- When did oxygenic photosynthesis arise on Earth?
- When did phototrophic life begin exerting control over the carbon cycle?

TOP SECRET

Trois sites mésoarchéens situés dans la Province Supérieure au Canada:

Red Lake Greenstone Belt	2,87 Ga
Woman Lake Greenstone Belt	2,86 Ga
Steep Rock Group	2,80 Ga

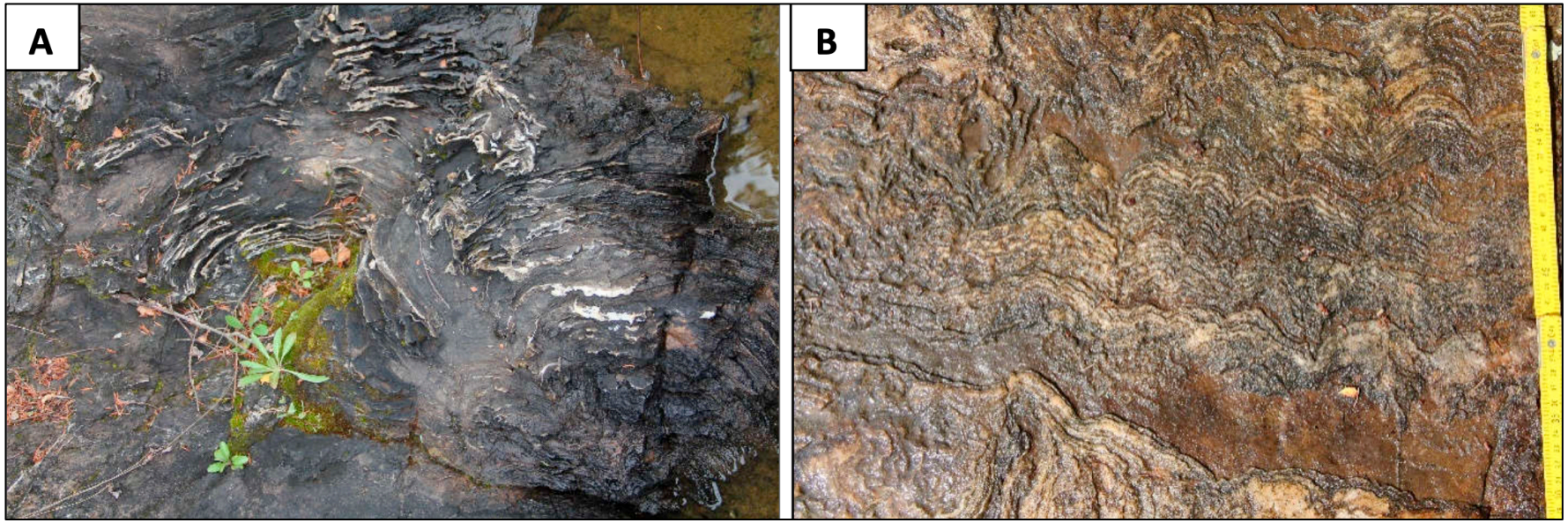
https://chalkboardpublishing.com/quizzes/topic-the-canadian-shield/



Modifié à partir de Kusky et Hudleston, 1999

Lithofaciès sédimentaires du Ball Assemblage au Red Lake

→ **plus de 200 m de carbonates** (dolomite et calcite), largement stromatolithiques, composés également de lits massifs de calcite et de couches de *crystal fans*

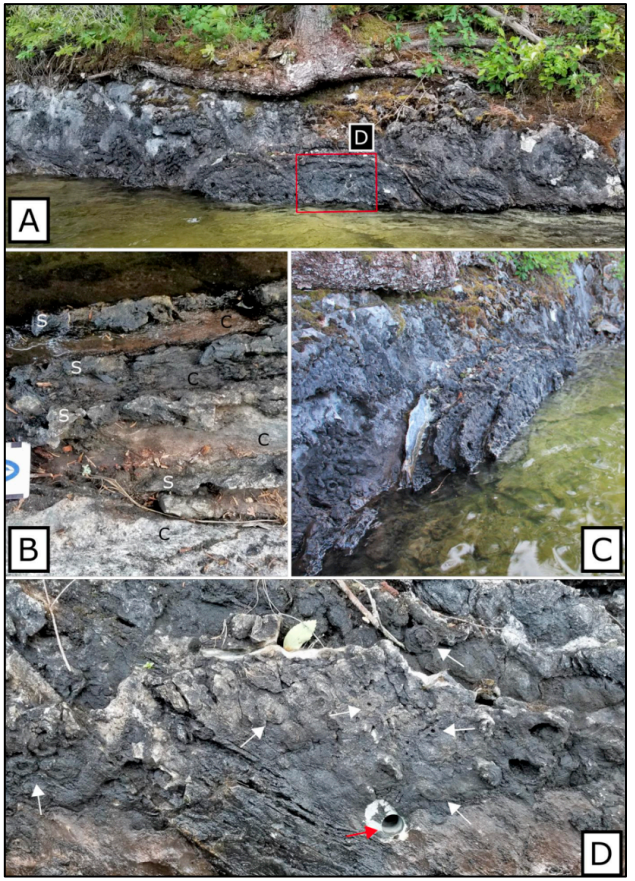


Stromatolithes dolomitiques en dômes (A) et stromatolithes calcitiques laminés (B) des carbonates de Red Lake. Photos de Afroz (2019)

Lithofaciès sédimentaires du Woman Lake Assemblage

→ **grande diversité de microbialites**:

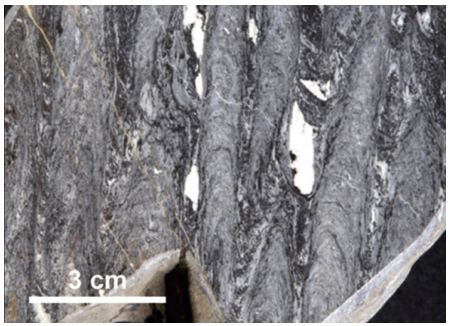
stromatolithes divers, thrombolithes, microbialites fenestrés

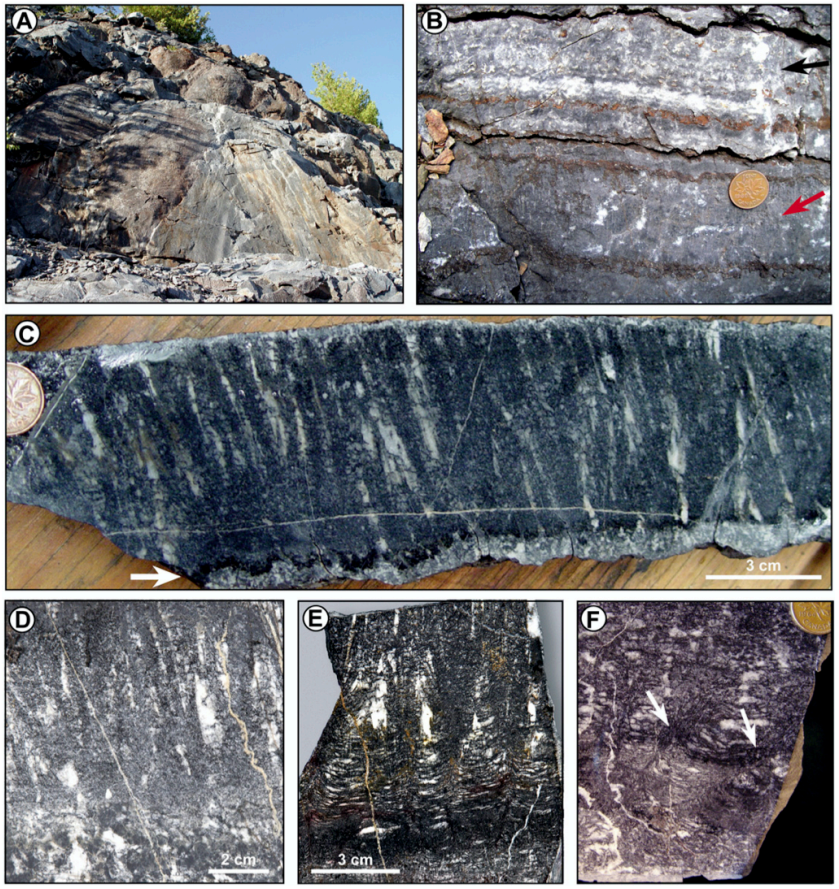


Photos provenant de Ramsay (2020)

Lithofaciès sédimentaires du Steep Rock Group

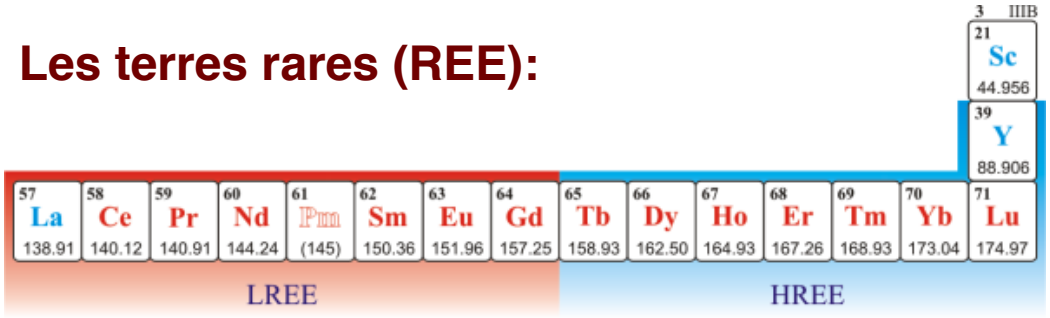
– **grande diversité de microbialites**, incluant des stromatolithes columnaires, stratiformes, fenestrés, dômes multi-métriques, et d'autres carbonates associés (*grainstones*, *crystal fans*)





Images provenant de Fralick et Riding (2015)

Les terres rares (REE):

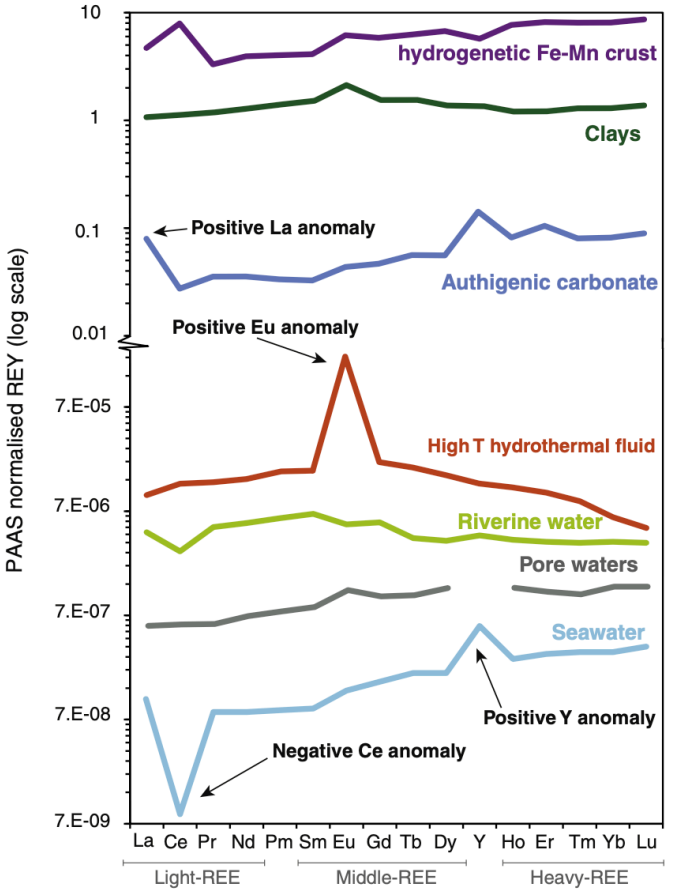


→ comportement géochimique cohérent sauf dans certaines conditions

→ **puissants traceurs paléo-environnementaux**

→ rayons ioniques modérés, ions chargés généralement (+III), peu mobiles et généralement **bien conservés** dans les **roches carbonatées**

→ fournissent des informations importantes sur la **composition de l'eau de mer** lors du dépôt des sédiments



Tostevin *et al.*, 2016

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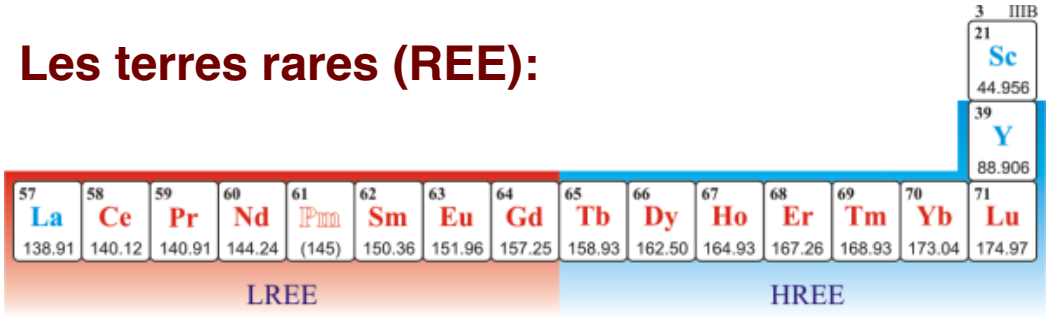


Plusieurs indicateurs utiles chez les REE (en incluant Y)

→ Anomalie en La (La/La*): salinité

→ Anomalie en Y/Ho: océan ouvert / fermé

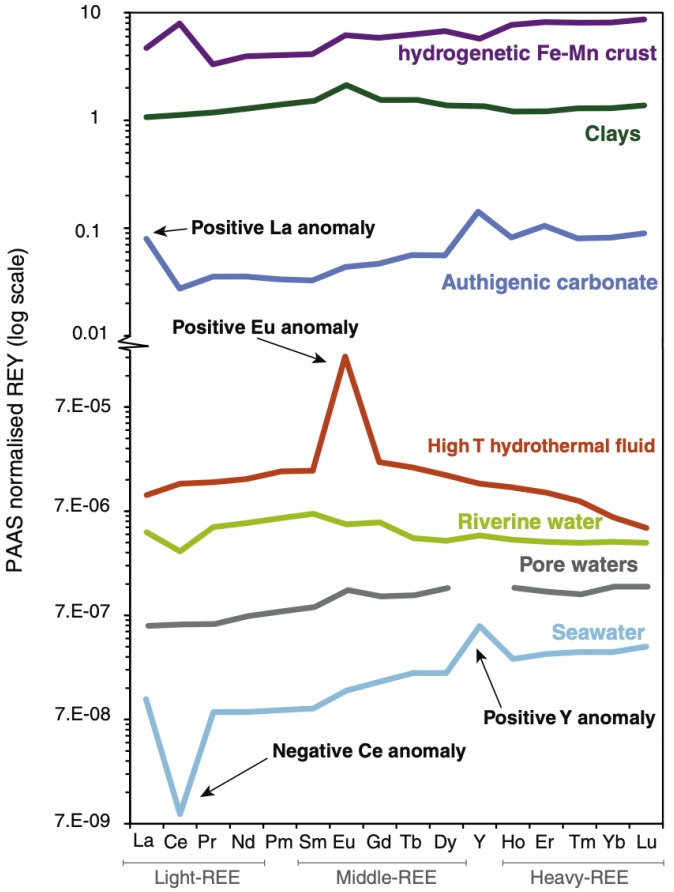
→ Enrichissement HREE: complexation $(REE)CO_3^{2-}$

→ Anomalie en Eu (Eu/Eu*): fluide haute température

→ Anomalie en Ce (Ce/Ce*): présence d'oxygène

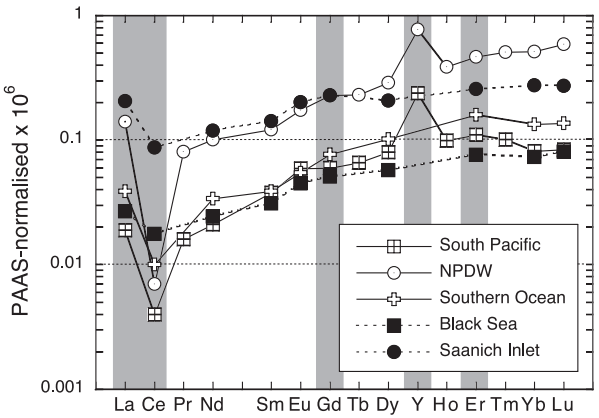
→ oxydation Ce(III) → Ce(IV)

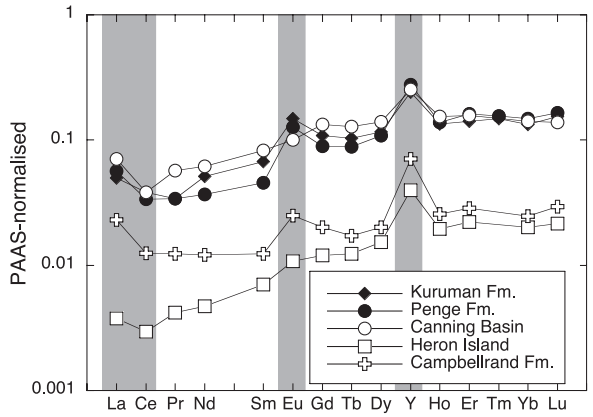
soluble → insoluble

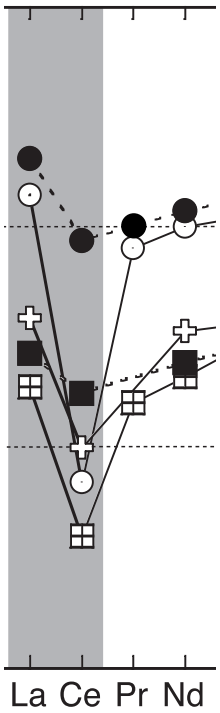


Tostevin *et al.*, 2016

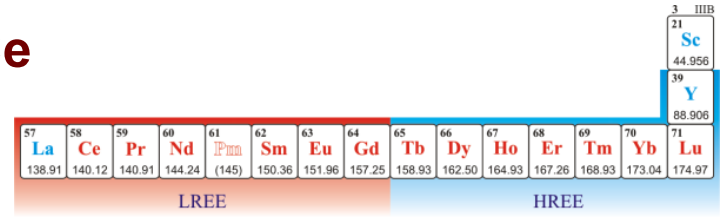
Zoom sur l'anomalie en Ce

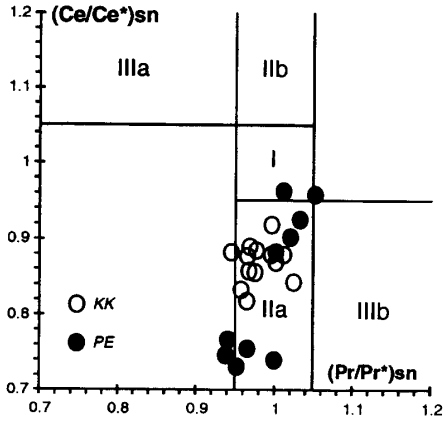






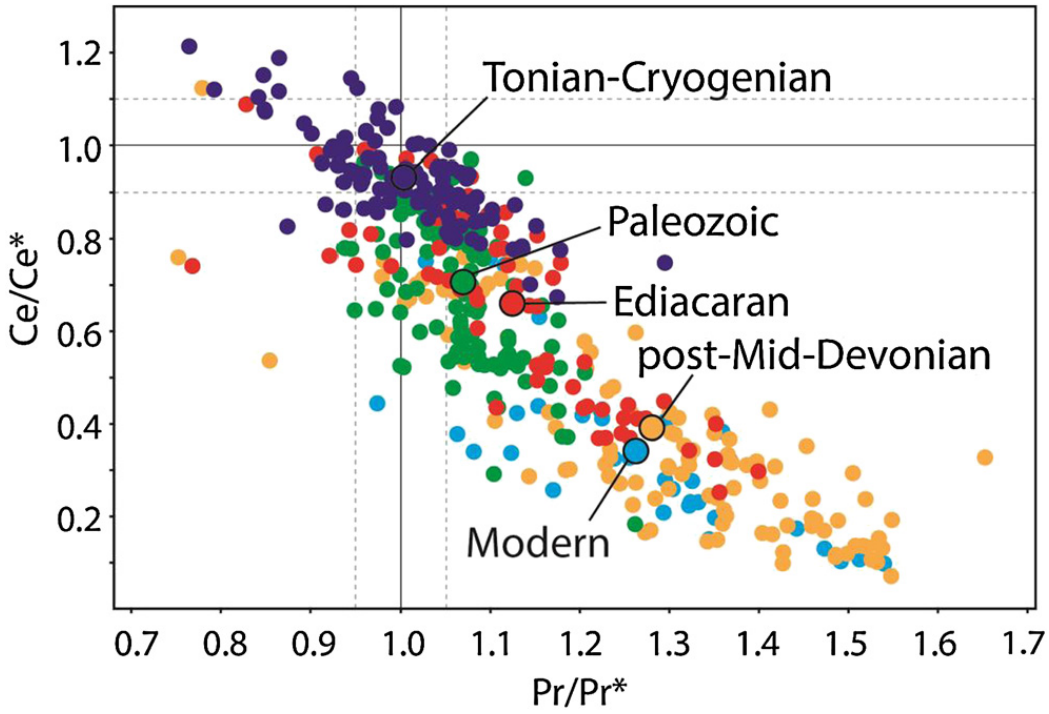
Bohlar et al (2004)





Bau and Dulski (1996)

Anomalies en Ce au cours du Phanérozoïque



Wallace et al. (2017)

Anomalie en Ce dans les carbonates

→ traceur de l'oxygénation marine

Méthodes

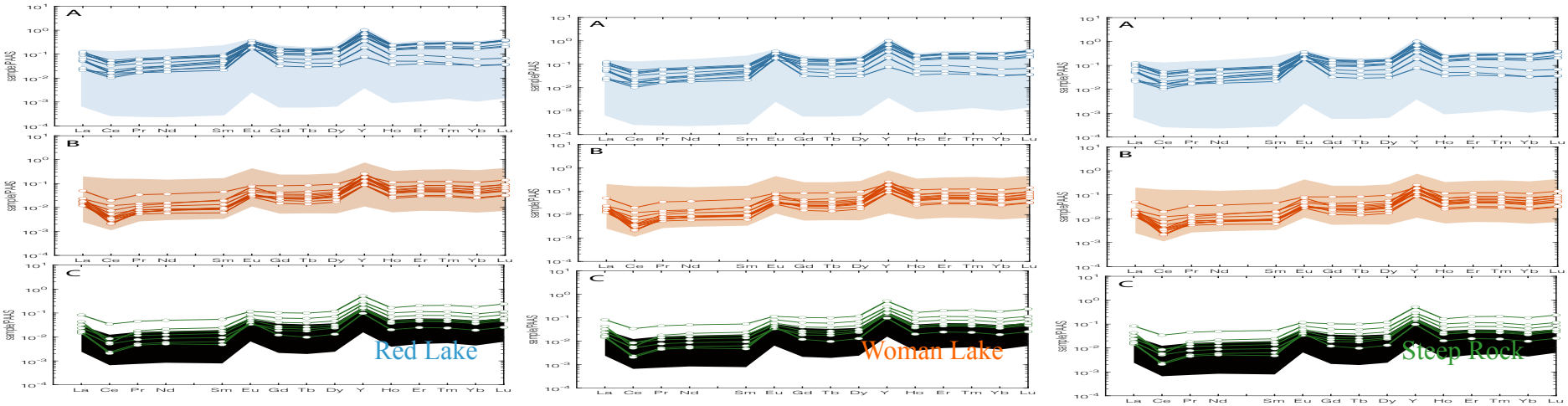
Digestion des échantillons carbonatés par « lessivage »,
5 % Acide acétique

→ pour éviter la dissolution des argiles et obtenir le signal authigénique des carbonates

Mesures des éléments traces sur HR-ICP-MS ElementXR

Effort collectif, **données obtenues par Patry** (Red Lake – NGI, ré-analyse de tous sites), **Homann, Sansjofre, Lalonde** et **Afroz** (Red Lake), **Ramsay** (Woman Lake), et **Wilmeth** (Steep Rock).

Résultats et Discussion



Zones colorées: toutes les données carbonates du projet ERC EARTHBLOOM

Spectres individuels: échantillons avec anomalie en Ce sélectionnés pour datation La-Ce et réanalysés pour cette étude

Datation radiométrique ^{138}La-^{138}Ce

La méthode de datation radiométrique La-Ce se base sur la **désintégration du ^{138}La vers le ^{138}Ce**

Temps de décroissance très long
→ nécessite très haute précision

Min requis: ~0.000001 (2SE) sur le rapport ^{138}Ce/^{142}Ce
→ 0.000000144 dans cette étude

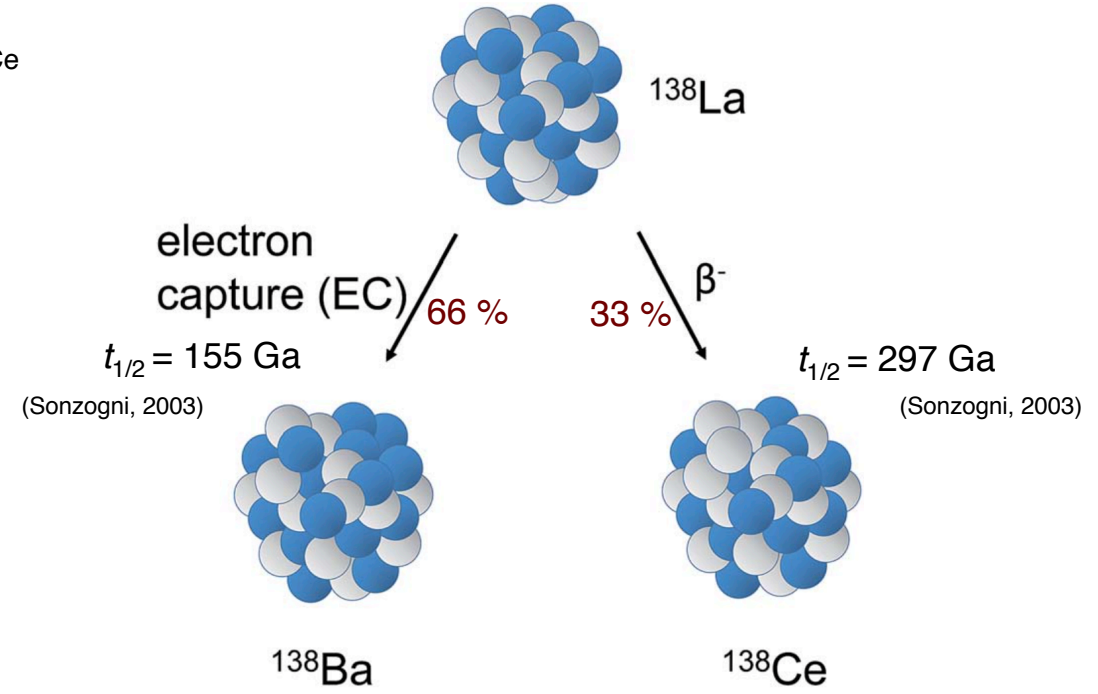


Schéma d'après Schnabel et al. (2017)

Méthodes

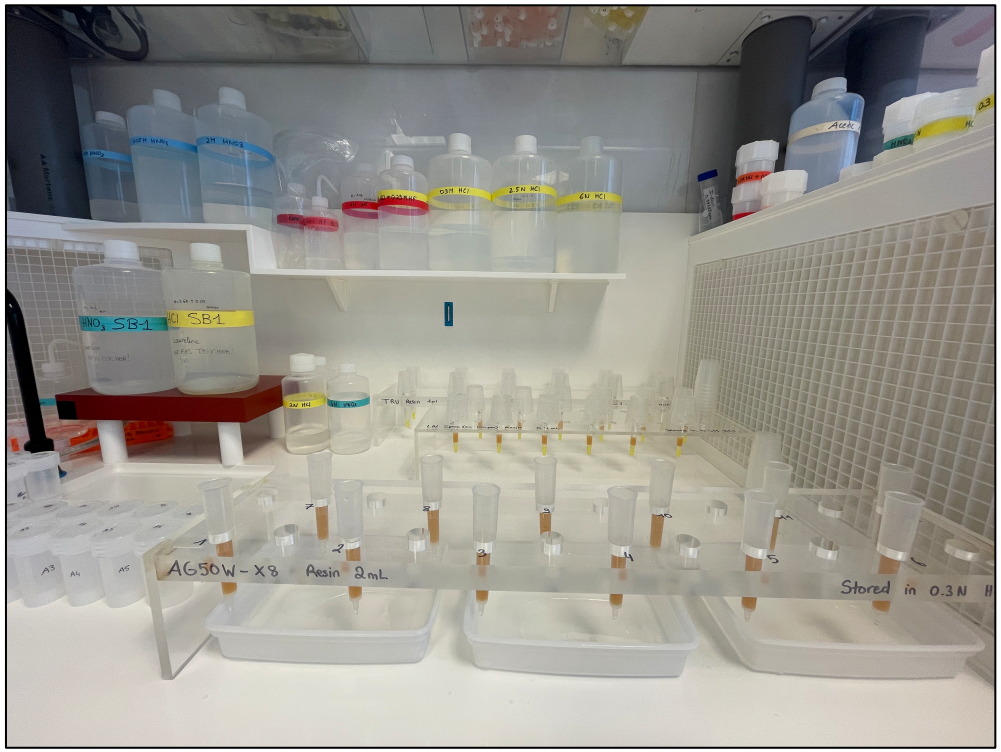
La **purification chimique du Ce** pour analyse nécessite le passage des échantillons à travers des **colonnes de résines échangeuses d'ions en quatre étapes**:

1re étape: résine TRU Spec

2e étape : résine AG50W-X8

3e étape : résine LN Spec

4e étape : résine AG50W-X8

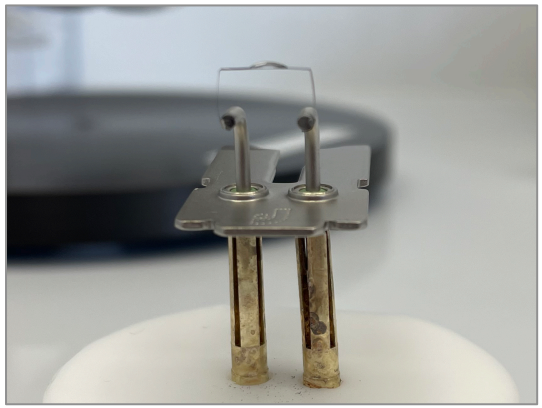


Analyses des isotopes de Ce par TIMS

Chargement sur filament Re
avec activateur H_3PO_4

Analyses sur Triton nº 619 de Brest
et Triton Plus du LMV (M. Boyet)

Analyses en oxydes
selon Bonnand et al. (2019)



Triton nº 619, GO, Brest

Triton Plus, LMV, Clermont Ferrand

Configuration des cages (*PT - mesures de peak tailing*):

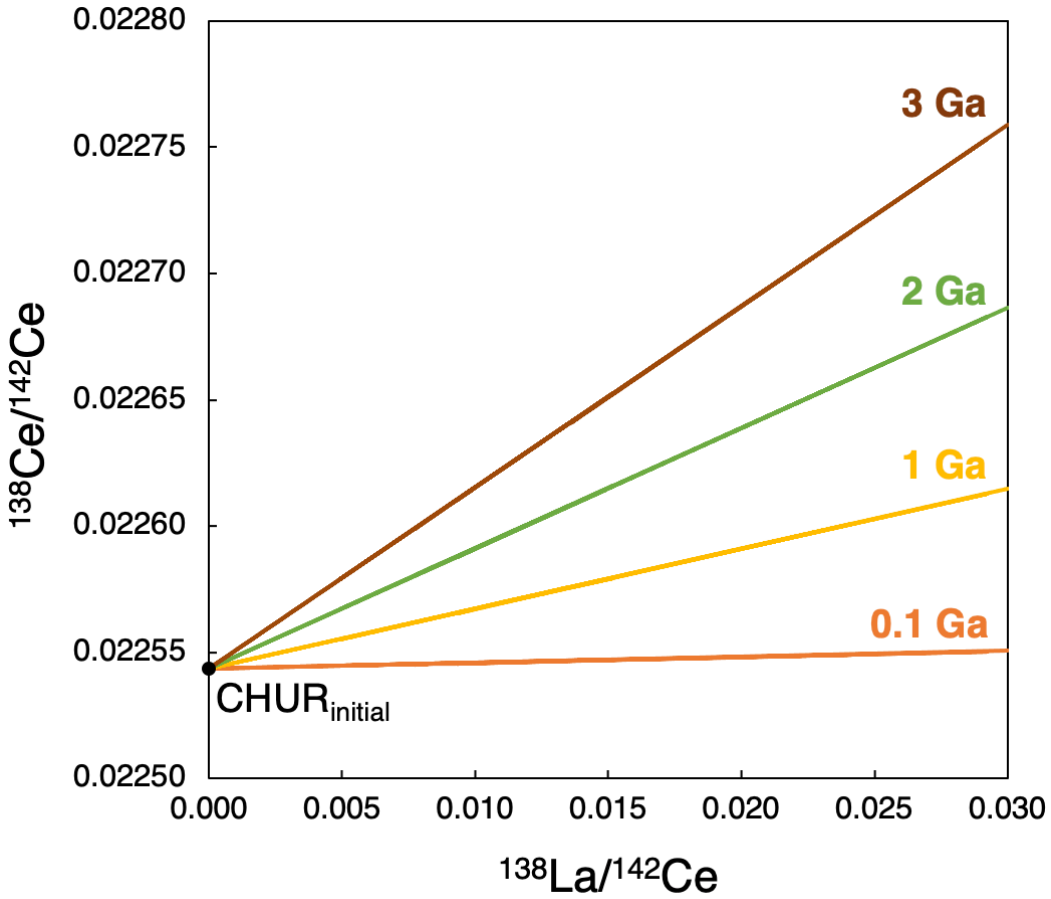
	L4	L3	L2	L1	C	H1	H2	H3	H4
Oxides	$^{134}Ba^{16}O$	$^{136}Ce^{16}O$	PT	PT	$^{138}Ce^{16}O$	PT	x	$^{142}Ce^{16}O$	$^{142}Ce^{18}O$
Masses	150	152	152.64	153.37	154	154.61	x	158	160

Résultats La-Ce

Un diagramme isochrone

→ différentes pentes pour différents âges

Nous pouvons **placer nos données sur des isochrones théoriques** prédites pour des anomalies en Ce d'âges divers



Résultats La-Ce

Rappel du diagramme isochrone

→ différentes pentes pour différents âges

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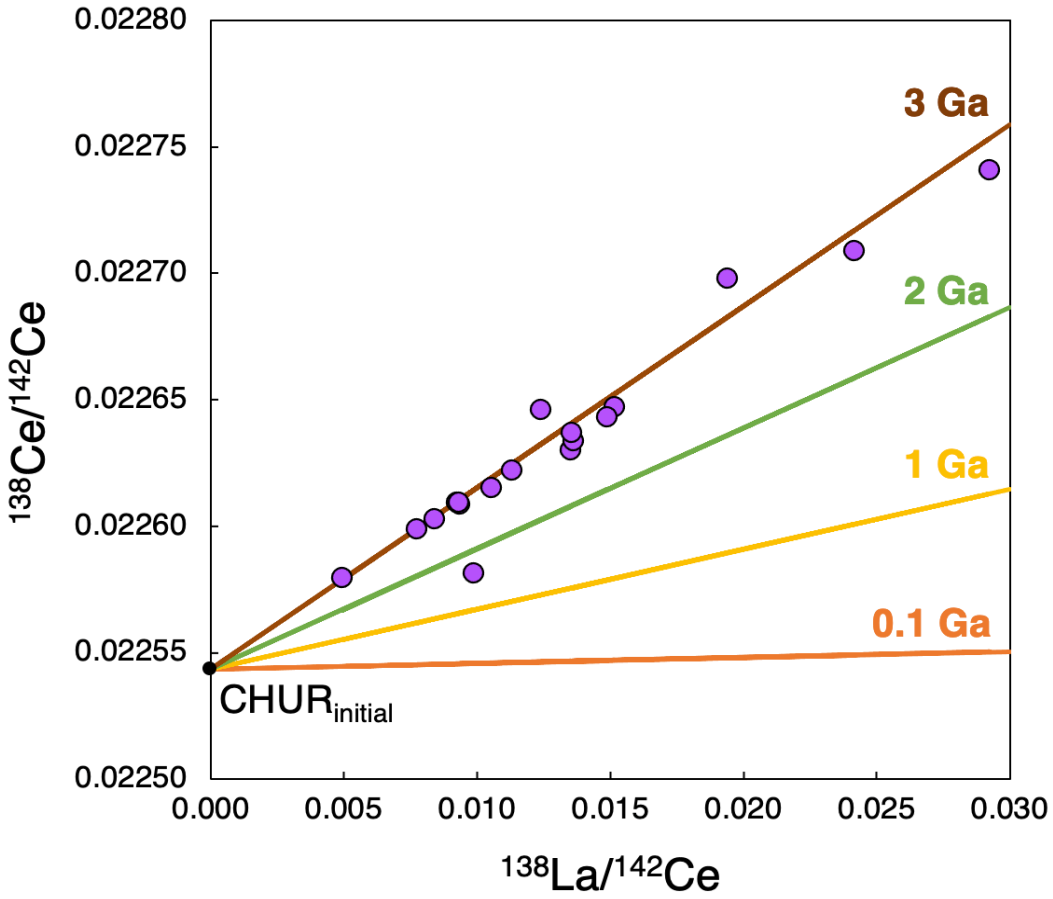

Résultats La-Ce

Rappel du diagramme isochrone

→ différentes pentes pour différents âges

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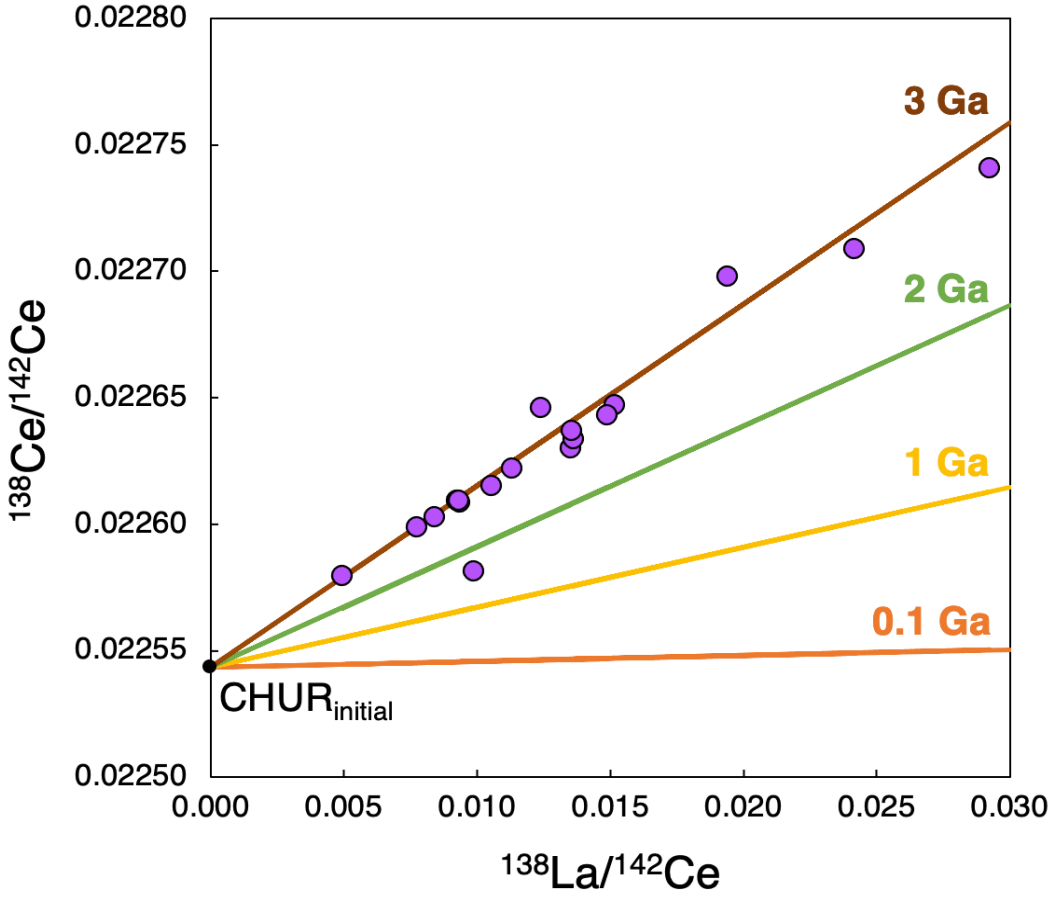
Les anomalies en Ce des trois plateformes mésoarchéennes **sont clairement anciennes**

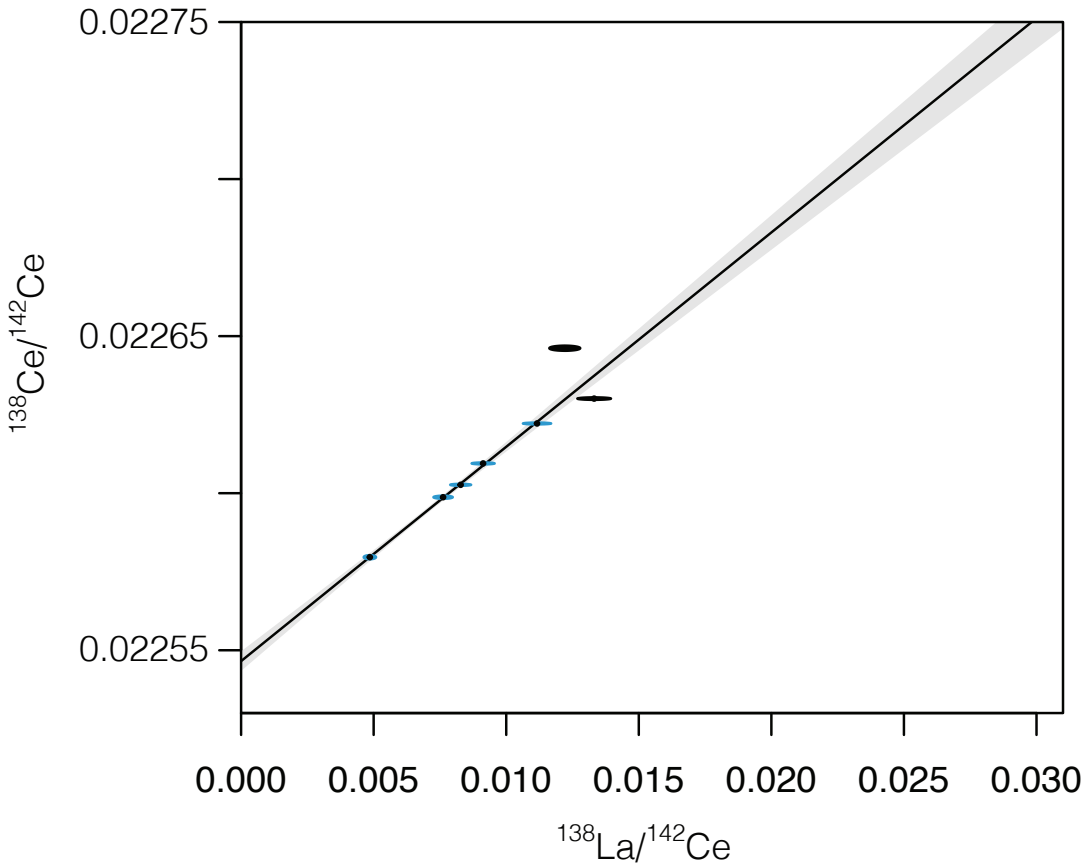
Regardons par la suite les données site par site…



Isochron La-Ce pour Red Lake

- **5 points** cohérents, deux *outliers*
- **Pente** de 0.00668 ± 0.00051
- **Intercept** de 0.0225469 ± 0.0000044
- **MSWD** = 0.19

Age de dépôt (par U-Pb):
2,868 ± 0,08 Ga



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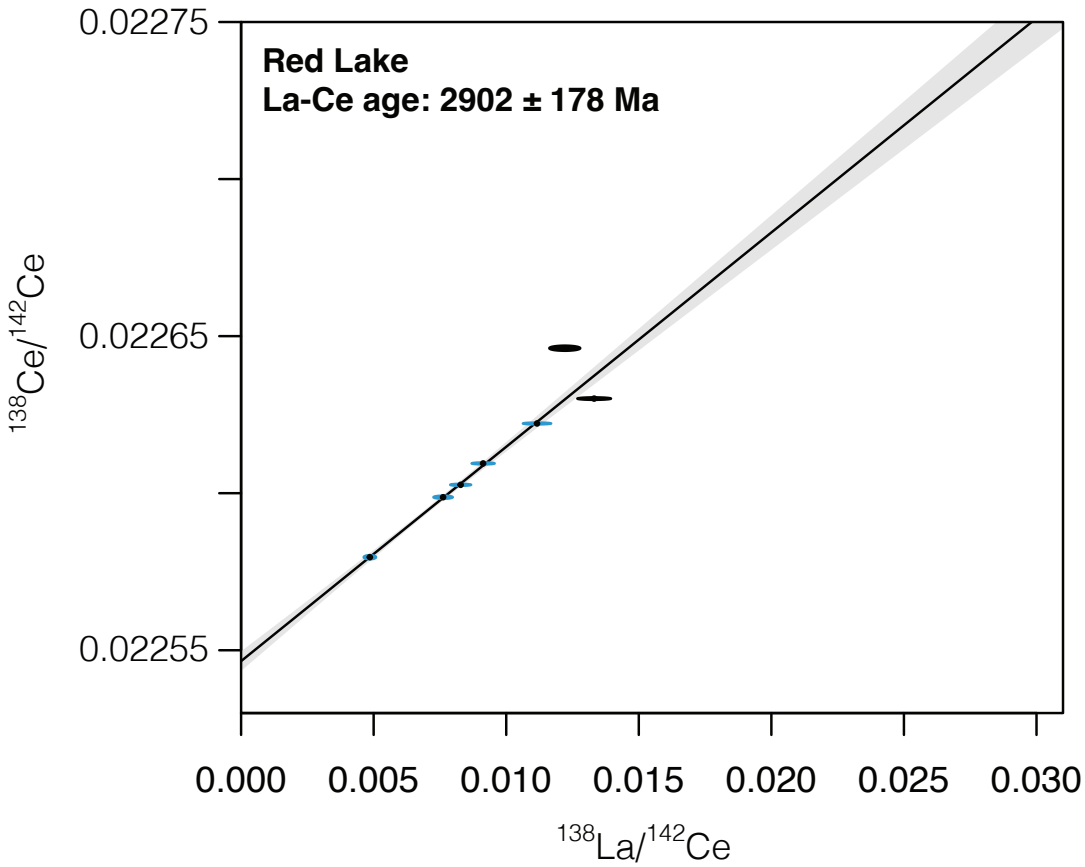
Age de dépôt (par U-Pb):
2,868 ± 0,08 Ga

Age de fermeture La-Ce:
2,90 ± 0,18 Ga

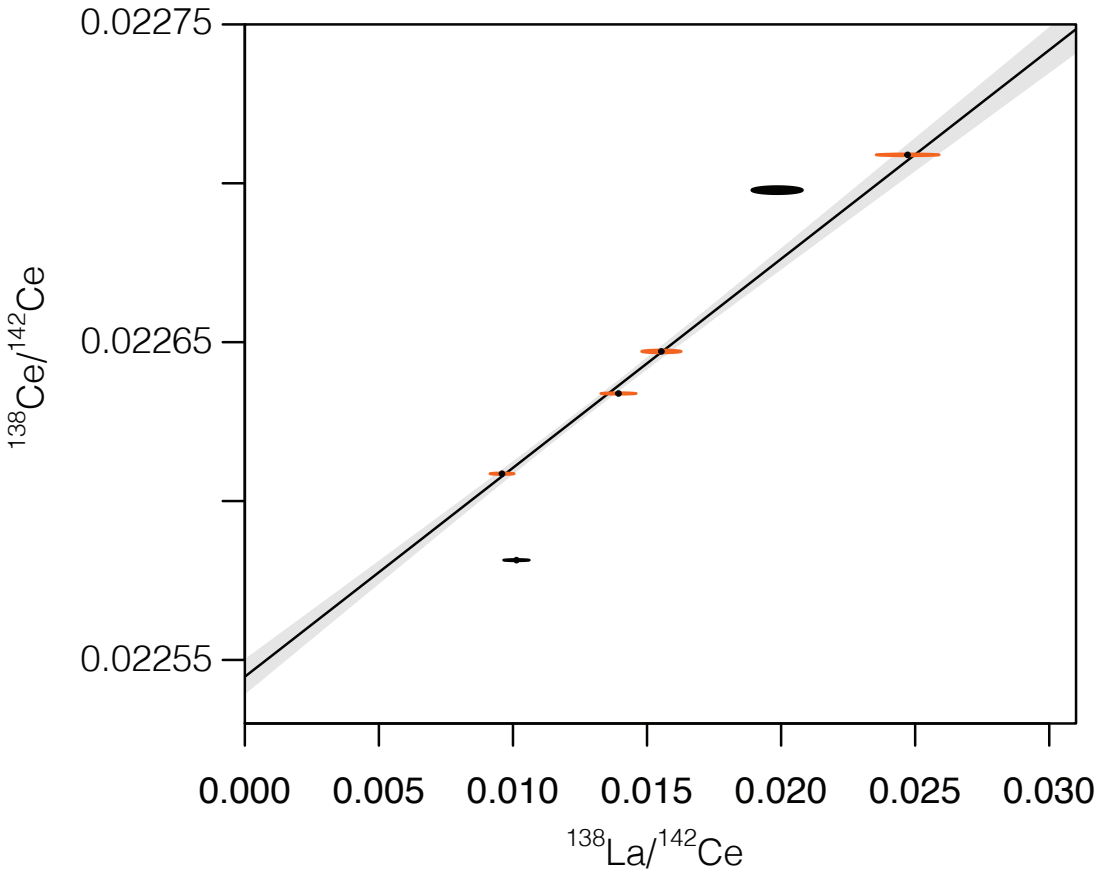
Confirmé Mésoarchéen



Isochron La-Ce pour Woman Lake

- **4 points** cohérents, deux *outliers*
- **Pente** de 0.00686 ± 0.00023
- **Intercept** de 0.0225427 ± 0.0000038
- **MSWD** = 2.7

Age de dépôt (par U-Pb):
2,86 ± 0,005 Ga



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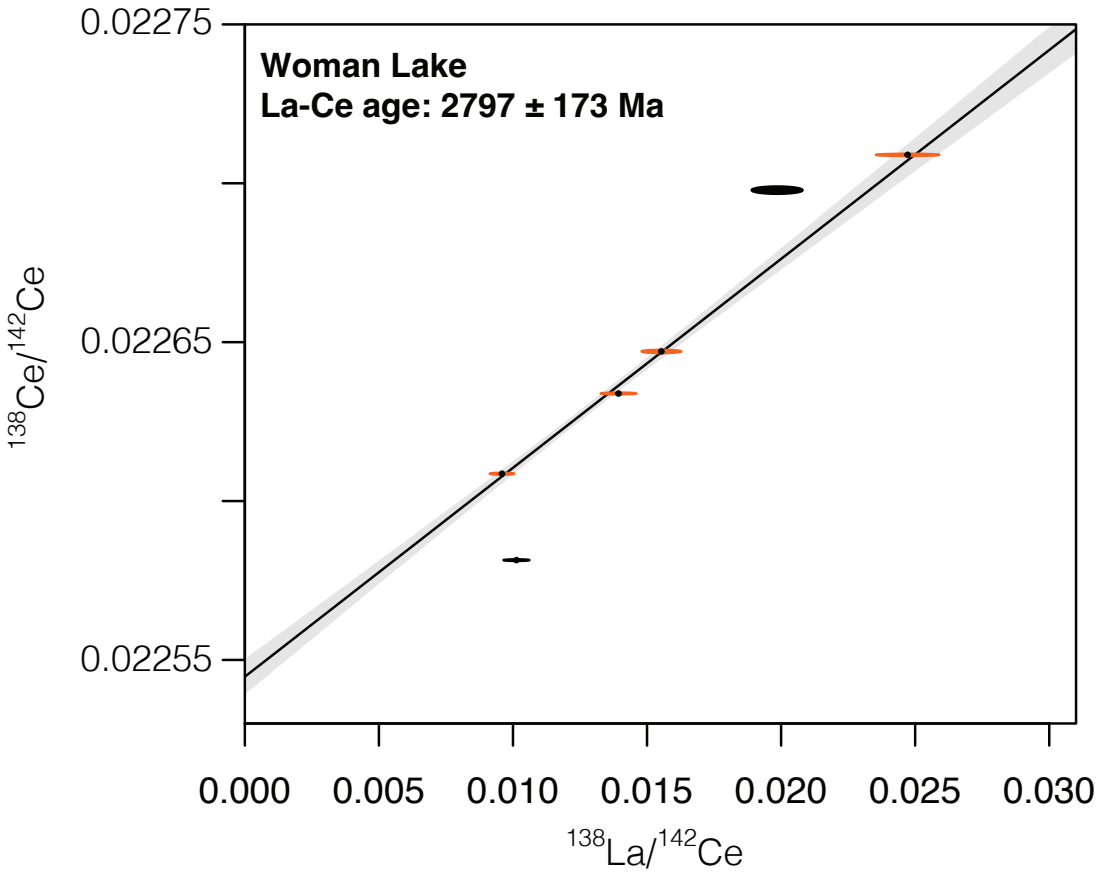
Age de dépôt (par U-Pb):
2,86 ± 0,005 Ga

Age de fermeture La-Ce:
2,80 ± 0,17 Ga

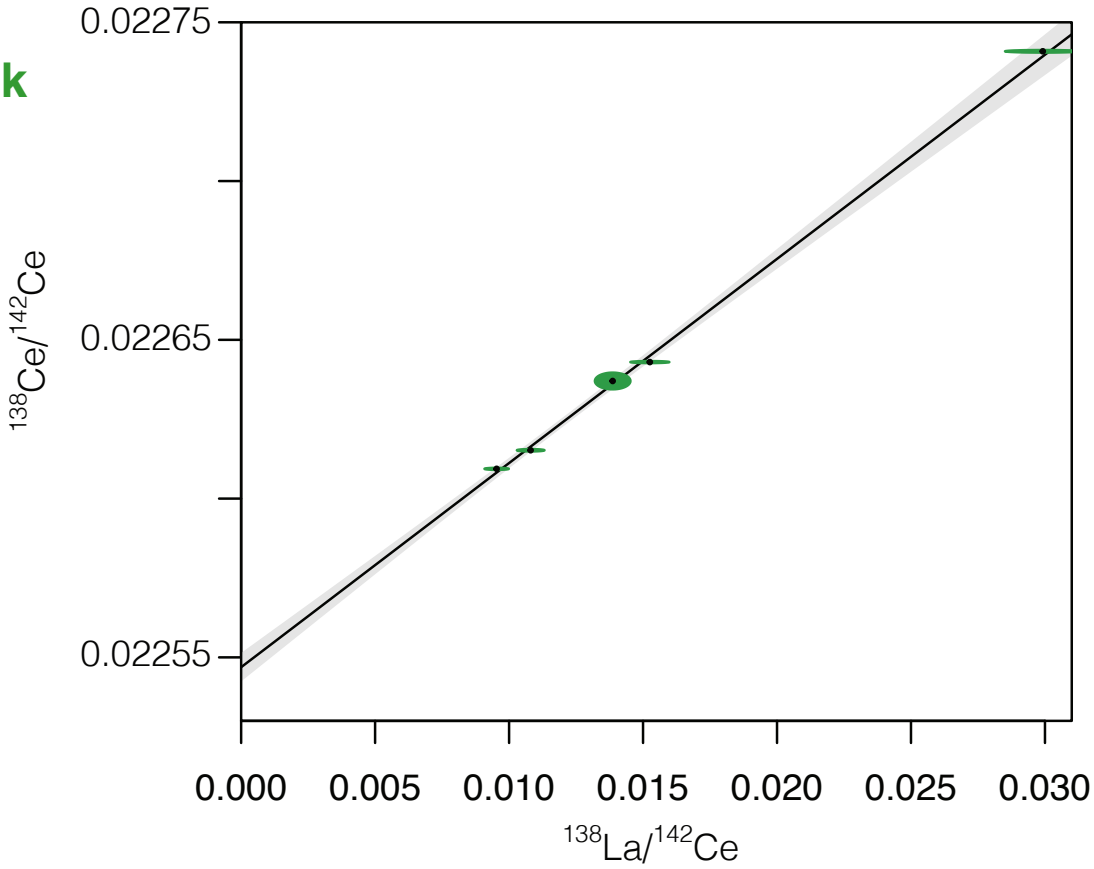
Confirmé Mésoarchéen



Isochron La-Ce pour Steep Rock

- **5 points** cohérents, zéro outliers
- **Pente** de 0.00666 ± 0.00015
- **Intercept** de 0.0225458 ± 0.0000025
- **MSWD** = 2

Age de dépôt (par U-Pb):
2,80 ± 0,011 Ga



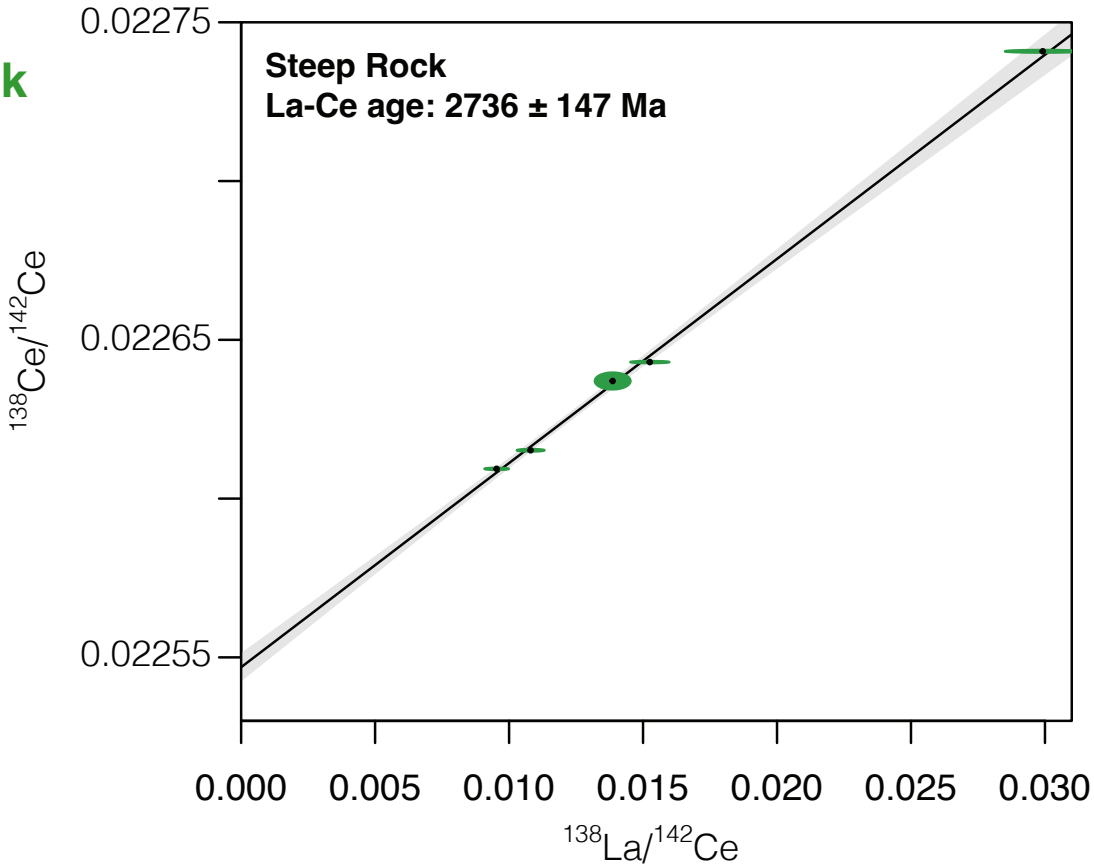
Isochron La-Ce pour Steep Rock

- **5 points** cohérents, zéro *outliers*
- **Pente** de 0.00666 ± 0.00015
- **Intercept** de 0.0225458 ± 0.0000025
- **MSWD** = 2

Age de dépôt (par U-Pb):
2,80 ± 0,011 Ga

Age de fermeture La-Ce:
2,74 ± 0,15 Ga

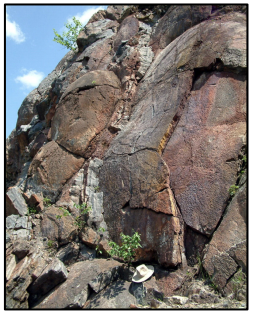
Confirmé Mésoarchéen



Conclusion

Datation radiométrique La-Ce appliquée aux carbonates stromatolithiques mésoarchéens: **Succès**

Pour les trois sites, les **anomalies en Ce sont primaires**



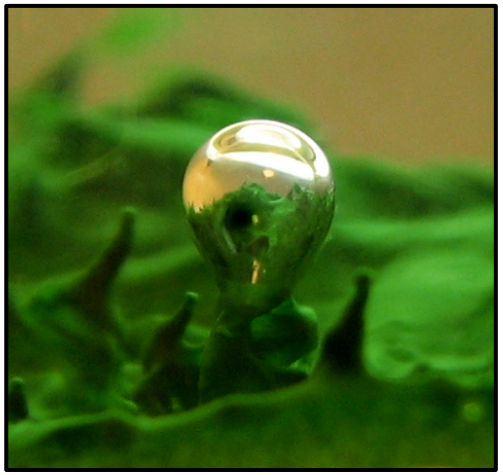


Photo: Tanya Bosak, MIT

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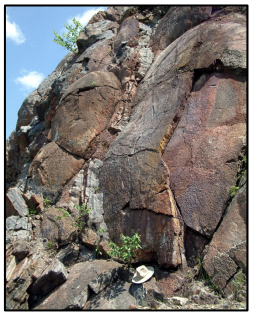

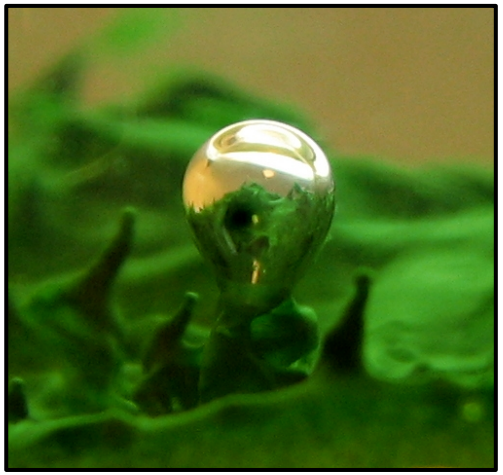

Photo: Tanya Bosak, MIT

Notre étude place fermement l'origine de la photosynthèse oxygénique à l'Archéen

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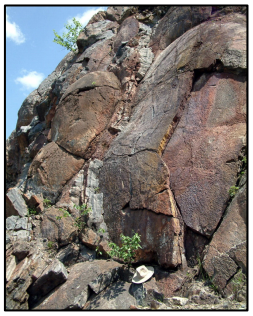

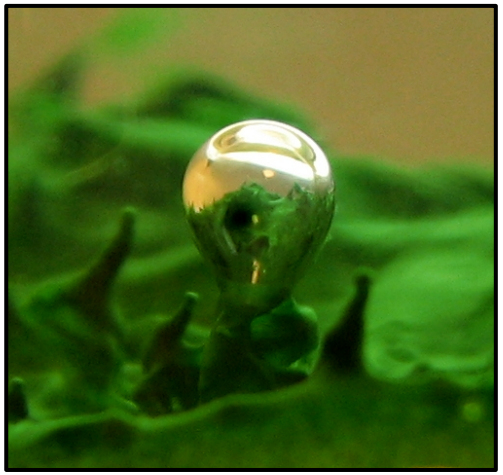

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Notre étude place fermement l'origine de la photosynthèse oxygénique à l'Archéen

Merci beaucoup
stefan.lalonde@univ-brest.fr