IV AstrobiON
Rio de Janeiro, Brazil,
2022

Building a bridge between Paleontology and Astrobiology

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Instituto de Ciência e Tecnologia
Universidade Federal dos Vales do Jequitinhonha e Mucuri
Diamantina, MG

Paleontology

Astrobiology

Building a bridge between Paleontology and Astrobiology

Paleontology

- ✓ From the Greek *palaios* = ancient + *ontos* = bein
  + *logo* dy
- ✓ Fossils
- ✓ From 10,000 years
  - ✓ Material < 10 Ky = subfossils

Spectrovenator rangei,
110 Ma
Minas Gerais, Brazil

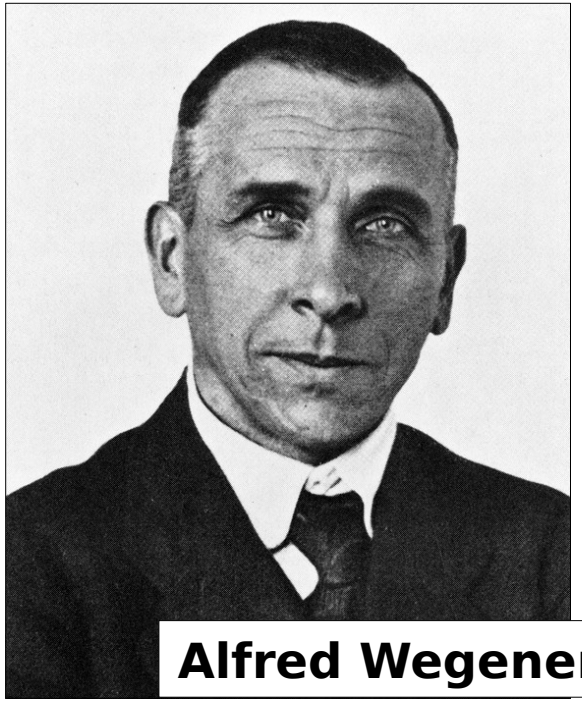
Application in:

- ✓ Evolution of the biosphere
- ✓ Earth System Evolution
- ✓ Dating of rocks
- ✓ Paleoecology
- ✓ Paleoenvironments/

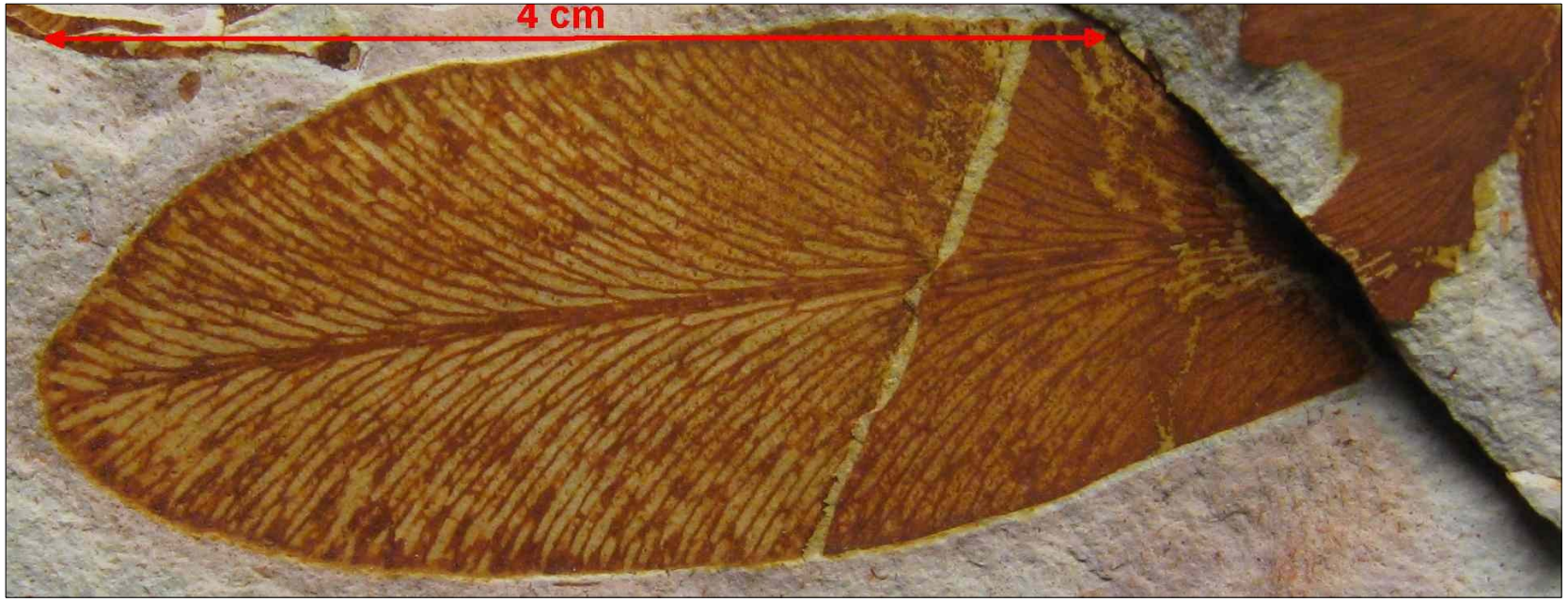
- ✓ Deposition of sedimentary basins
- ✓ Stratigraphic correlations
- ✓ Paleogeography/plate tectonics
- ✓ Oil industry applications $$$
- ✓ Astrobiology

Mesosaurus tenuidens
Brazil/Uruguay – Namibia/South Africa, Permian

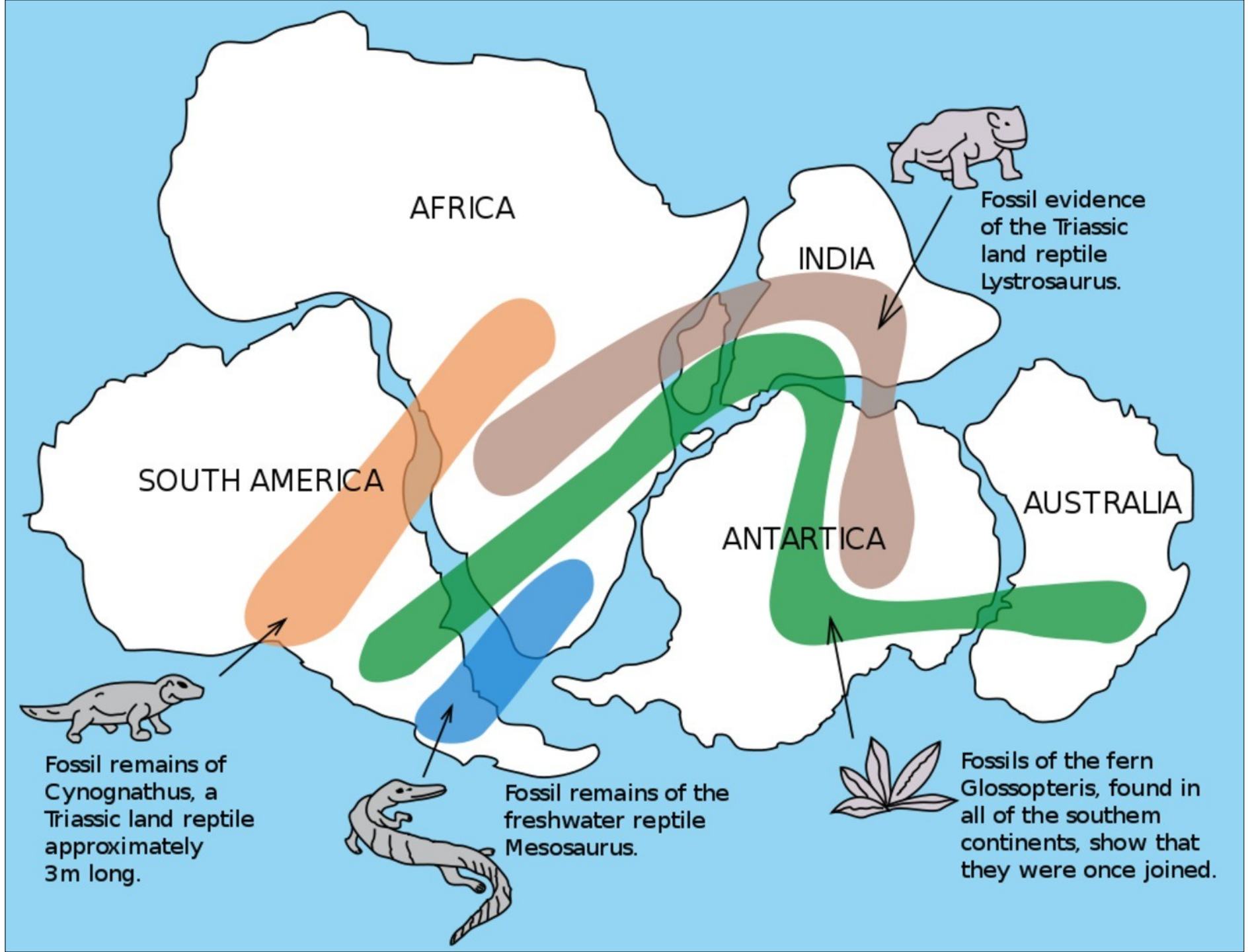
Glacial sequences



Alfred Wegener



***Glossopteris* sp.,** Gondwana, Devonian


AFRICA
INDIA
SOUTH AMERICA
ANTARTICA
AUSTRALIA
Fossil evidence of the Triassic land reptile Lystrosaurus.
Fossil remains of Cynognathus, a Triassic land reptile approximately 3m long.
Fossil remains of the freshwater reptile Mesosaurus.
Fossils of the fern Glossopteris, found in all of the southem continents, show that they were once joined.

Paleontology

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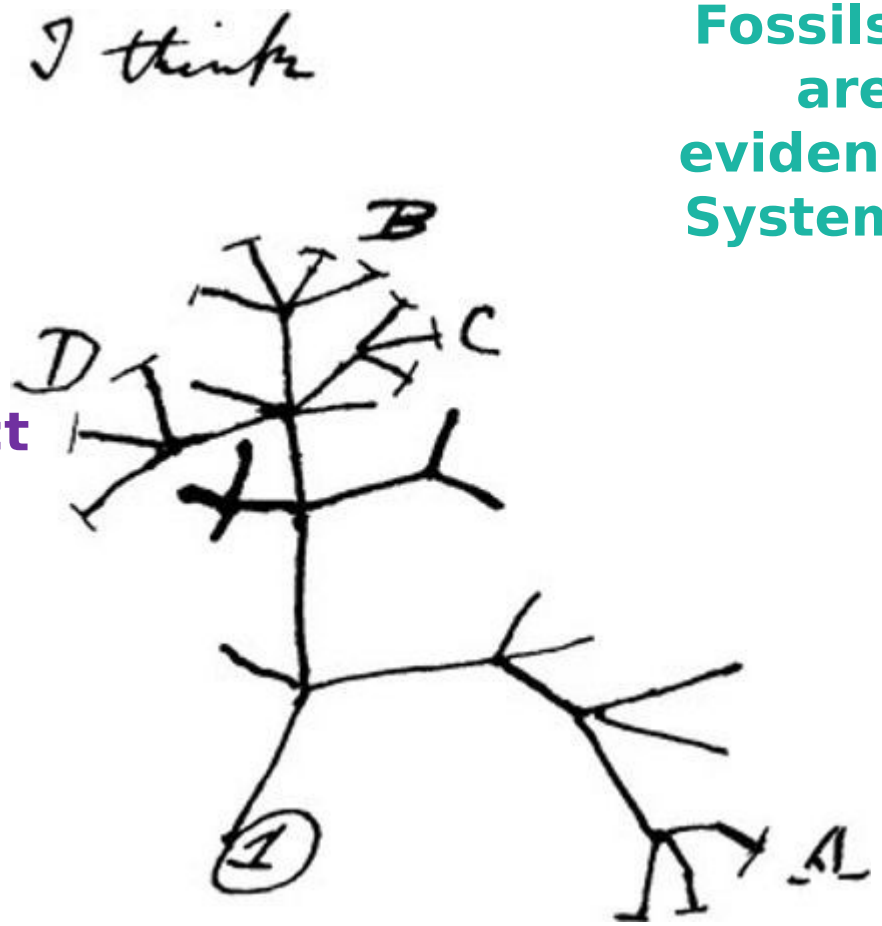
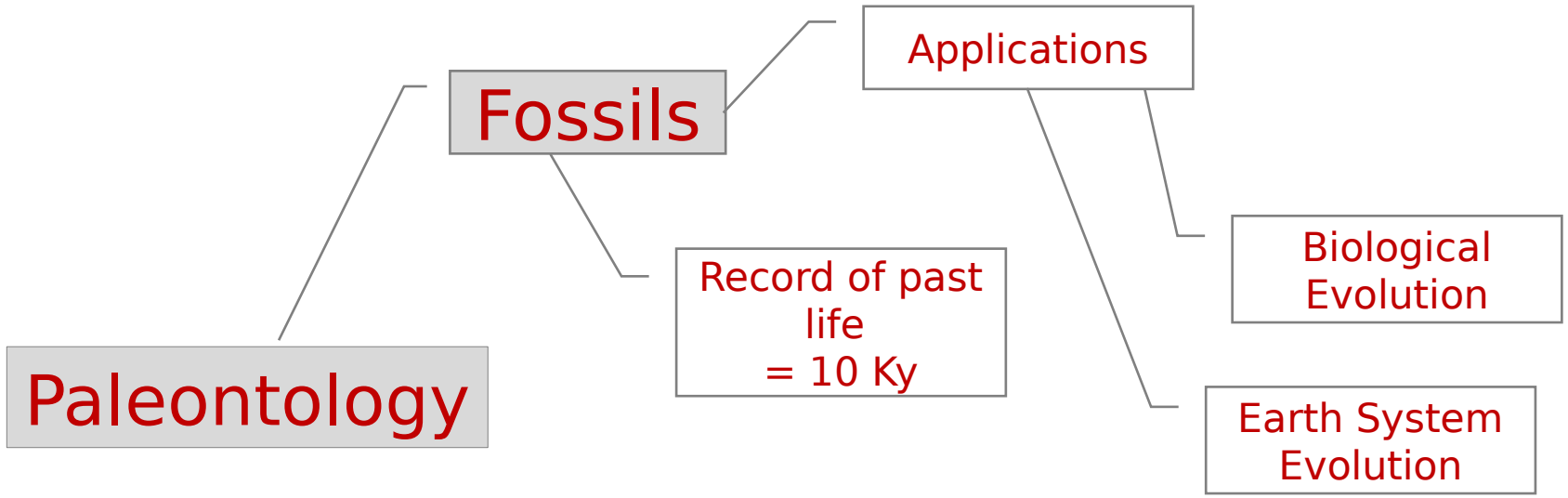
Paleontology

Fossils are direct evidence of Biological Evolution

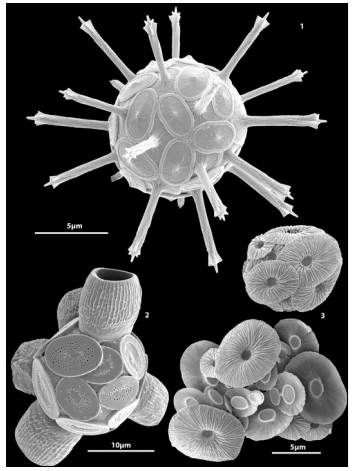


Fossils and rocks are the direct evidence of Earth System evolution


Paleontology
Fossils
Record of past life = 10 Ky
Applications
Biological Evolution
Earth System Evolution

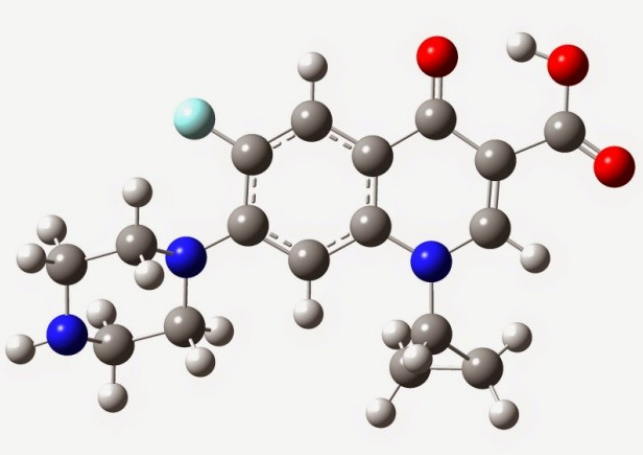
Types of Fossils

Body fossils



Trace fossils = Ichnofossils

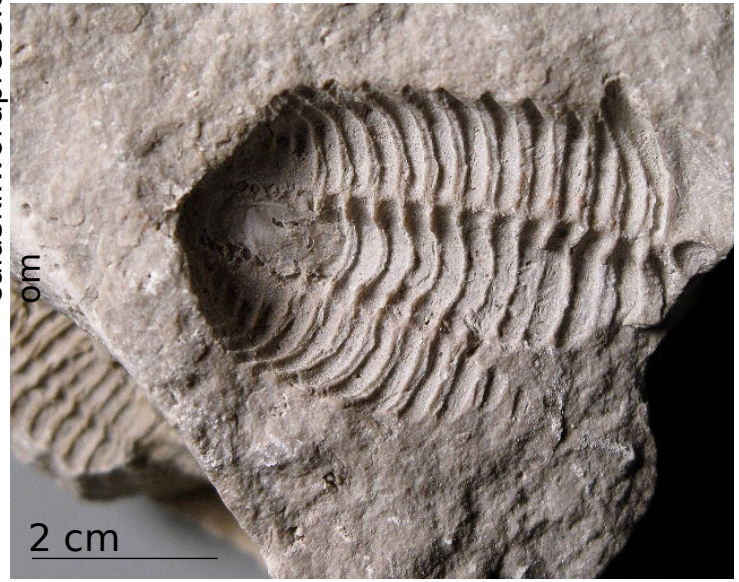
Types of Fossils



Biomarkers =
Chemical fossils

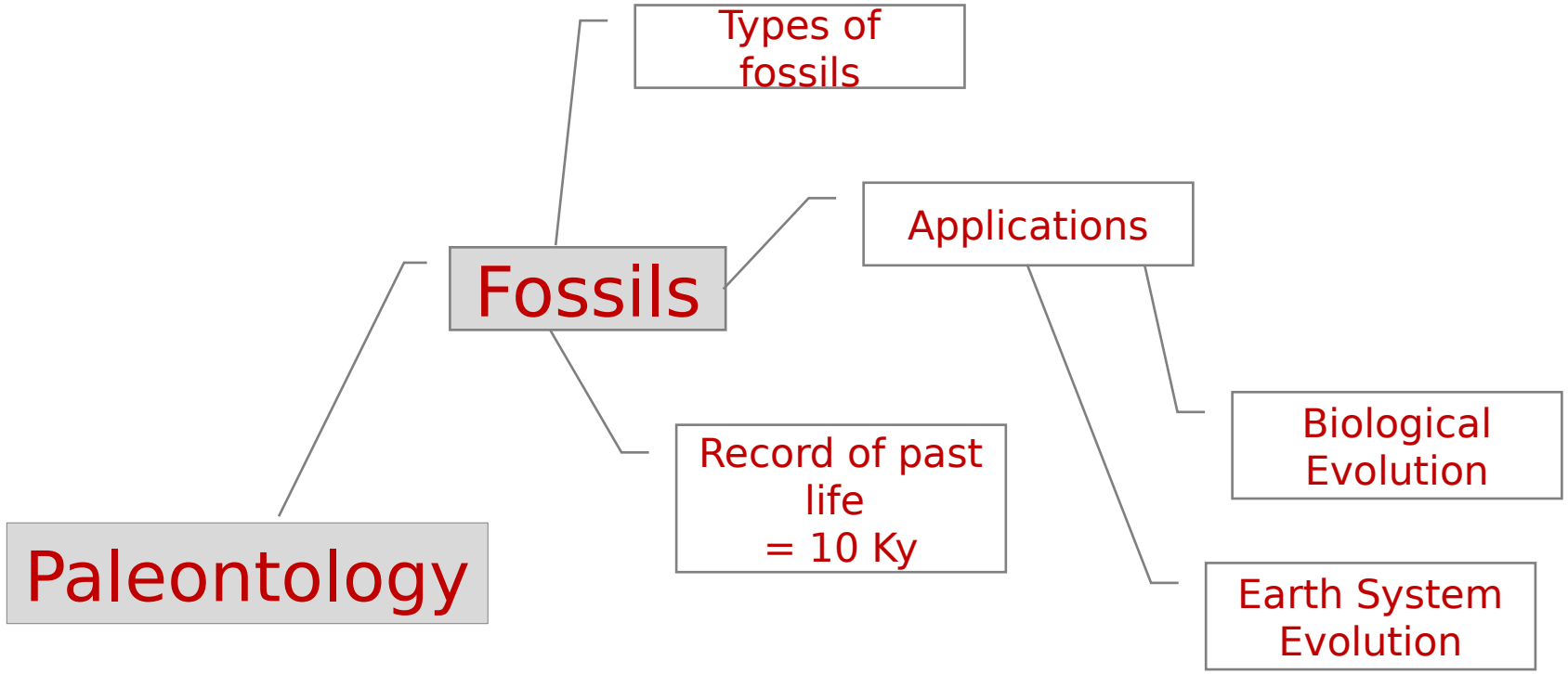
Pinterest.com

Casts



calaski.wordpress.com

Molds


Paleontology
Fossils
Types of fossils
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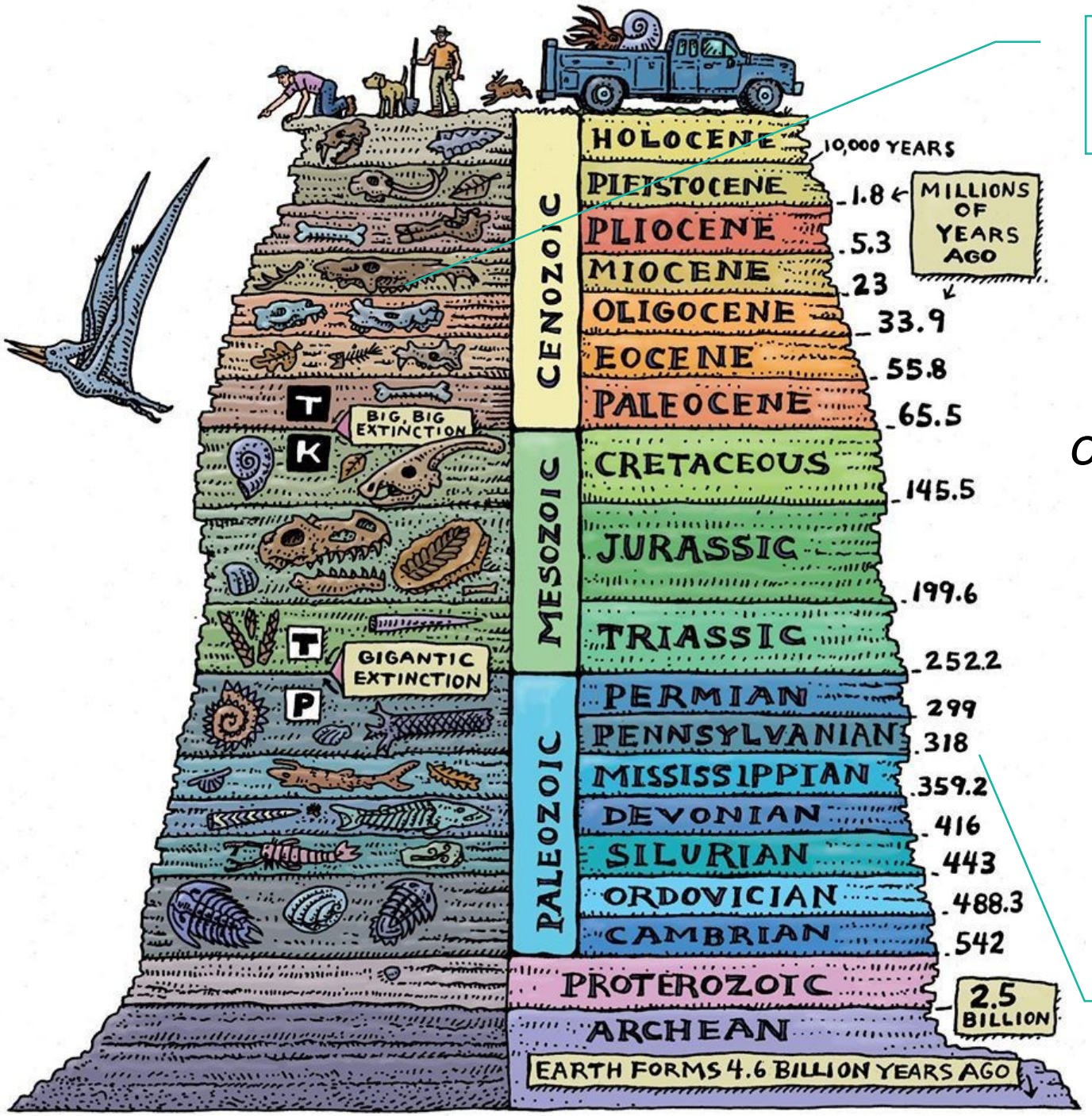


Relative age dating
(based mainly on fossils)

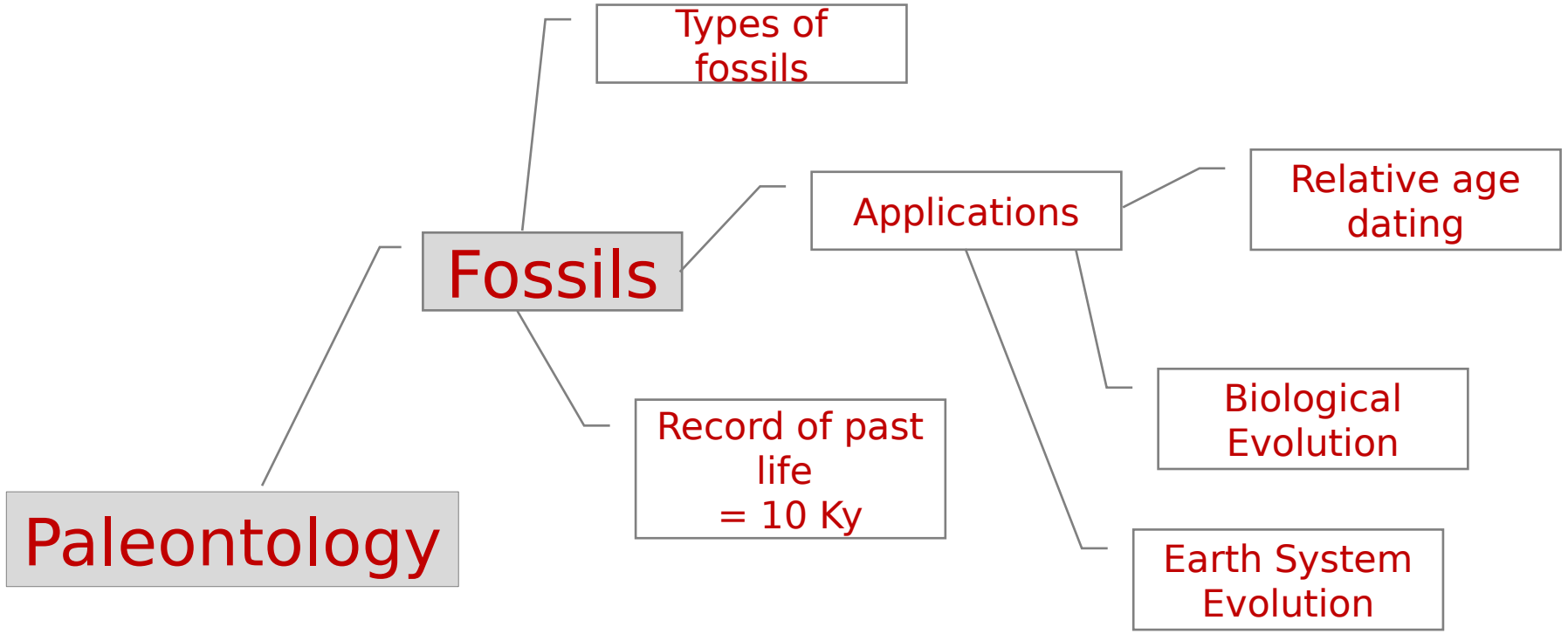
Geological Time

"...the extensive interval of time occupied by the geologic history of Earth."
@Britannica

4.55 billion years (Ga)

Geological Time Scale

Absolute age dating
(based on isotope half-life)


Paleontology
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Paleontology ✔

Astrobiology

Building a bridge between Paleontology and Astrobiology

Astrobiology

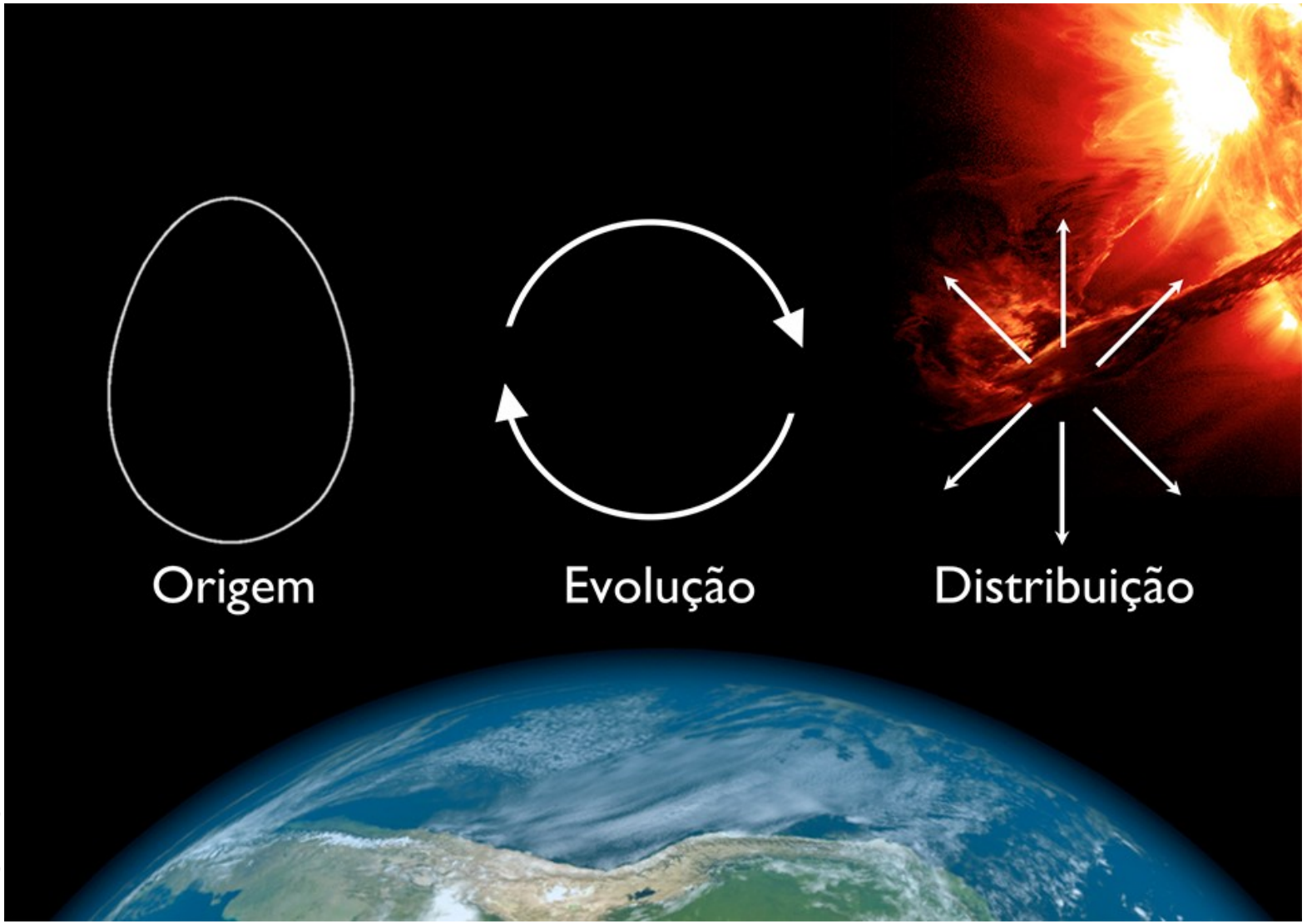
“Astrobiology, in the current view, is defined as a field of research dedicated to understanding the origin, evolution, distribution and future of life, on Earth or beyond.”
(Rodrigues et al., 2016).

“Astrobiology addresses questions about the past, future, extent, and interconnection of living things in the universe.”
(NASA roadmap, 2015)

“… the study of how life interacts with the planets, moons, and other objects in our universe.” (Blumberg, 2003).

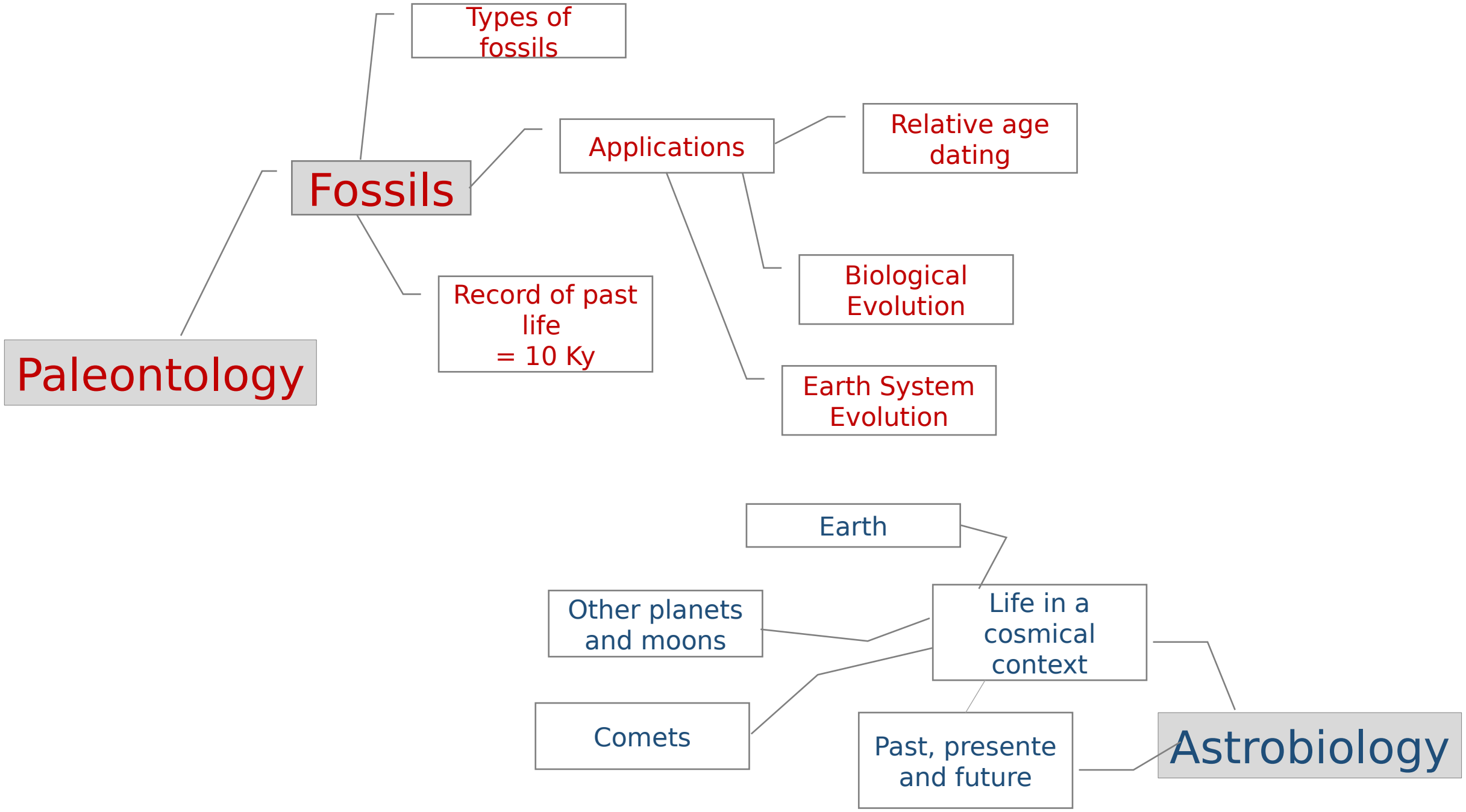
Astrobiology + definition = 81.100 results

Astrobiology



Life in the context of the Universe

Multidisciplinary science


Paleontology
Fossils
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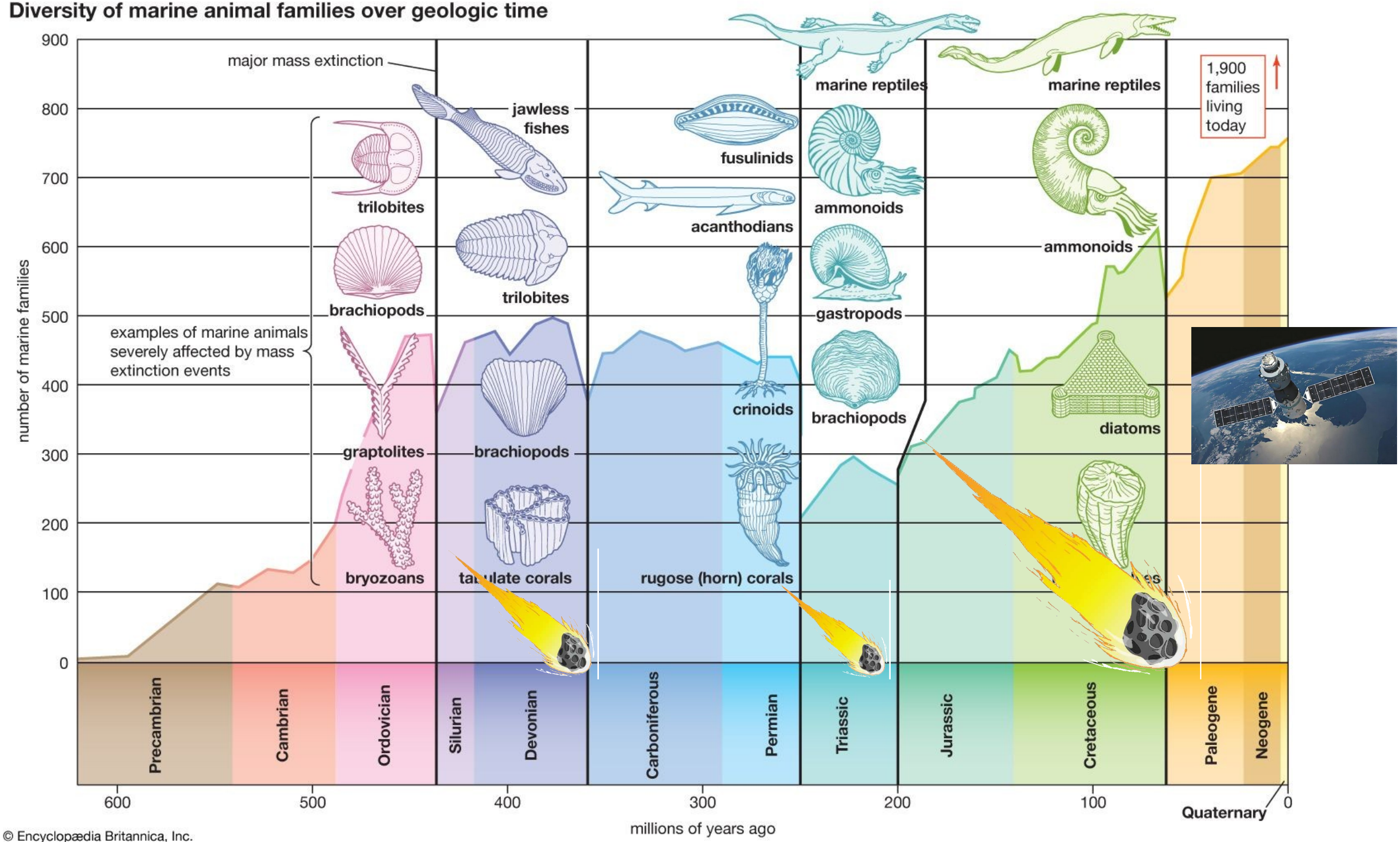
Astrobiology
Life in a cosmical context
Earth
Other planets and moons
Comets
Past, presente and future

Diversity of marine animal families over geologic time



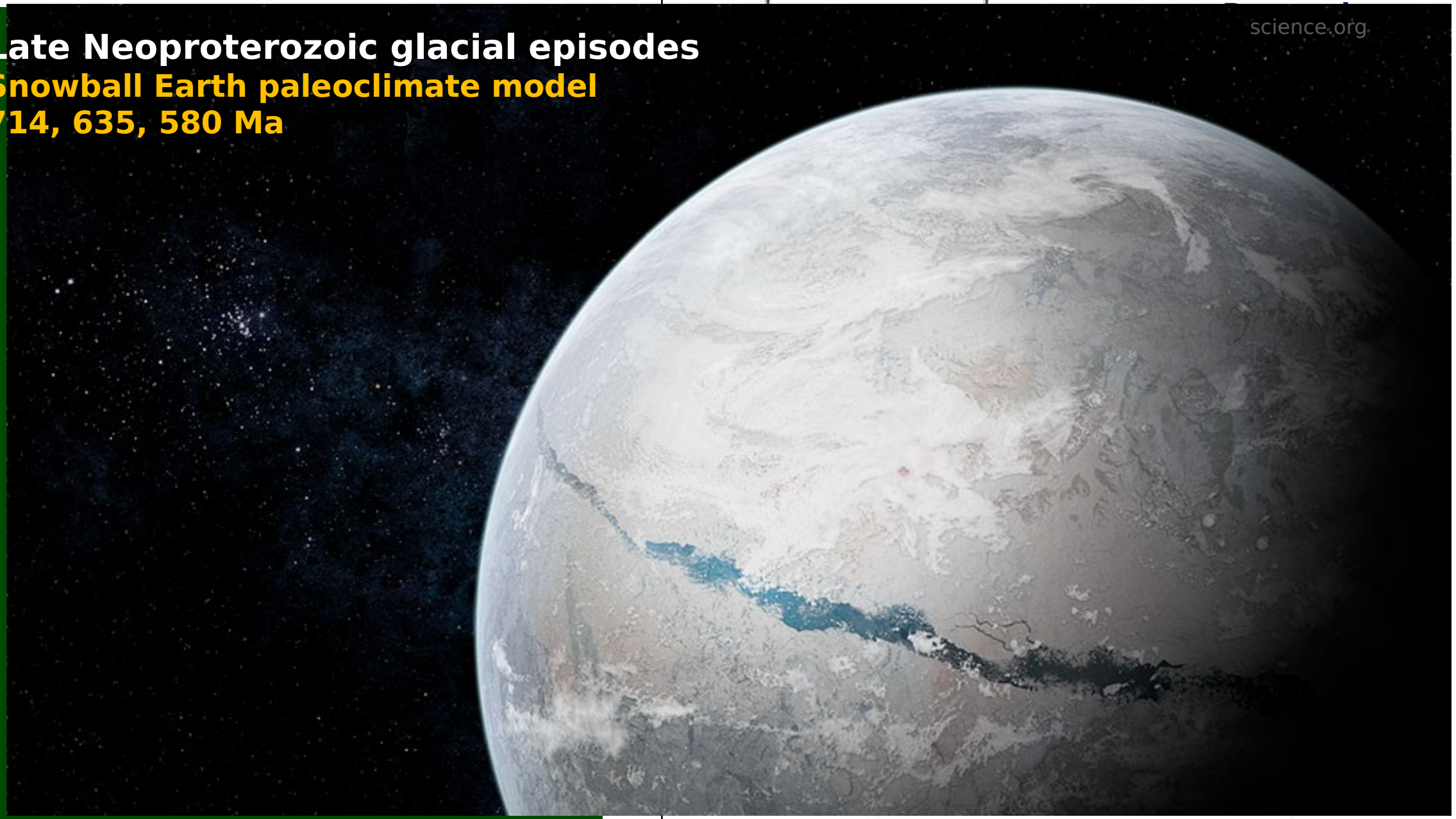
Hancock Summit, Pahranagat Range, Nevada


Woodleigh crater
Western Australia
@Wikipedia

Late Neoproterozoic glacial episodes

Snowball Earth paleoclimate model

714, 635, 580 Ma



Types of fossils

Fossils

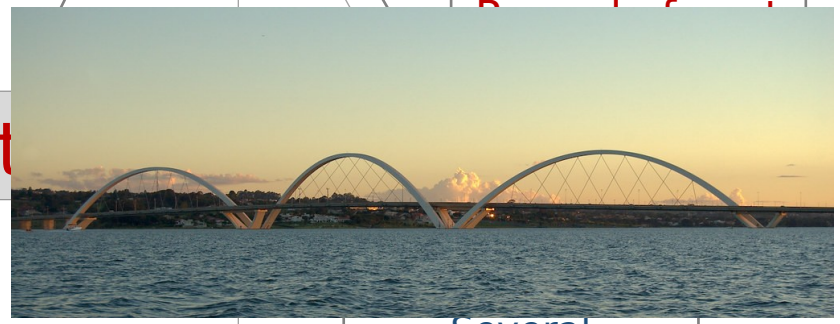
Applications

Relative age dating

Biological Evolution

Earth System Evolution

Paleont



Several examples in the geological record

Earth

Past, presente and future

Other planets and moons

Life in a cosmical context

Comets

Astrobiology

Paleontology ✔

Astrobiology ✔

Building a bridge between Paleontology and Astrobiology

Identifying abiotic sources of organic compounds

Synthesis and function of macromolecules in the origin of life

Early life and increasing complexity

Co-evolution of life and the physical environment

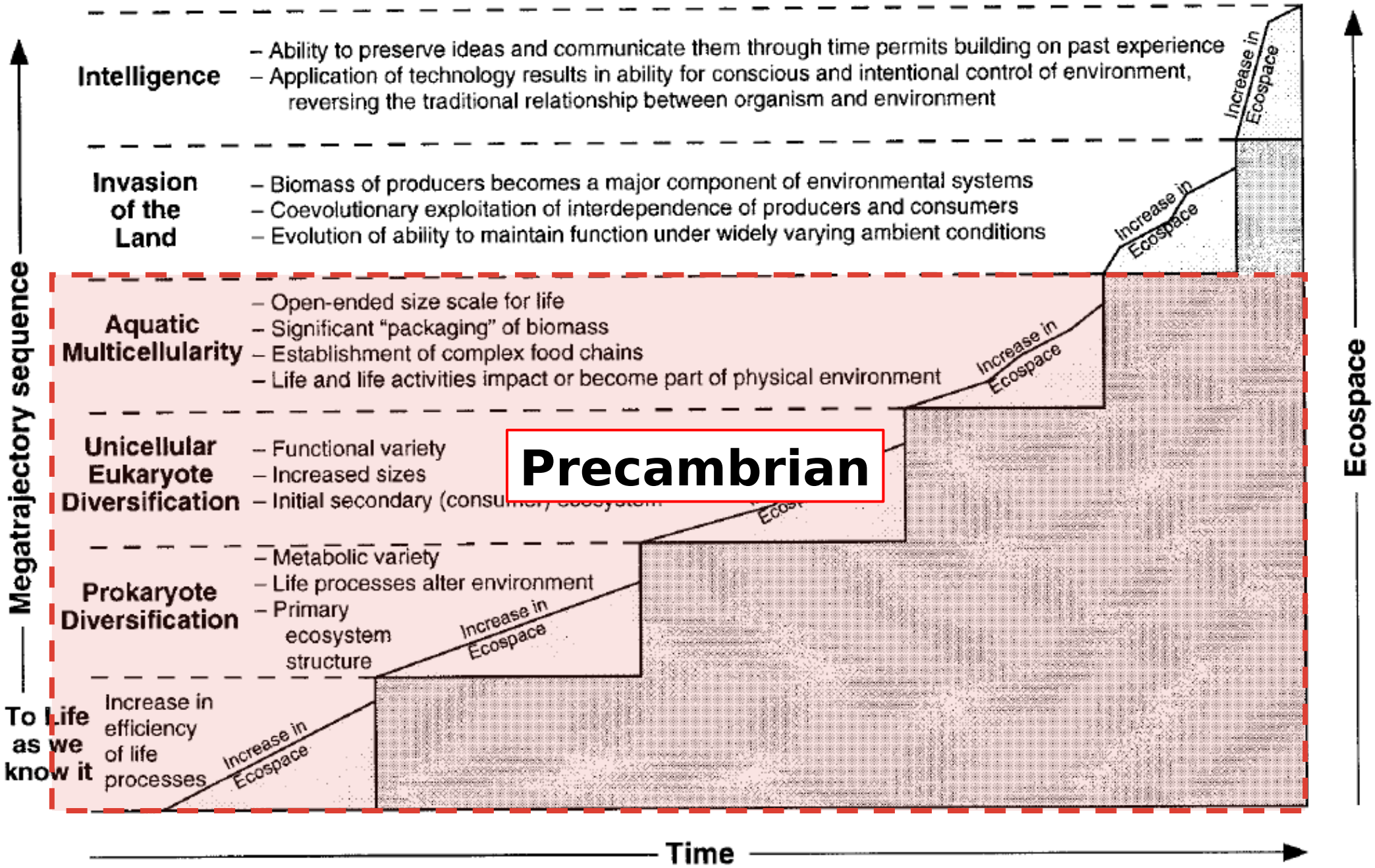
Identifying, exploring, and characterizing environments for habitability and biosignatures

Constructing habitable worlds

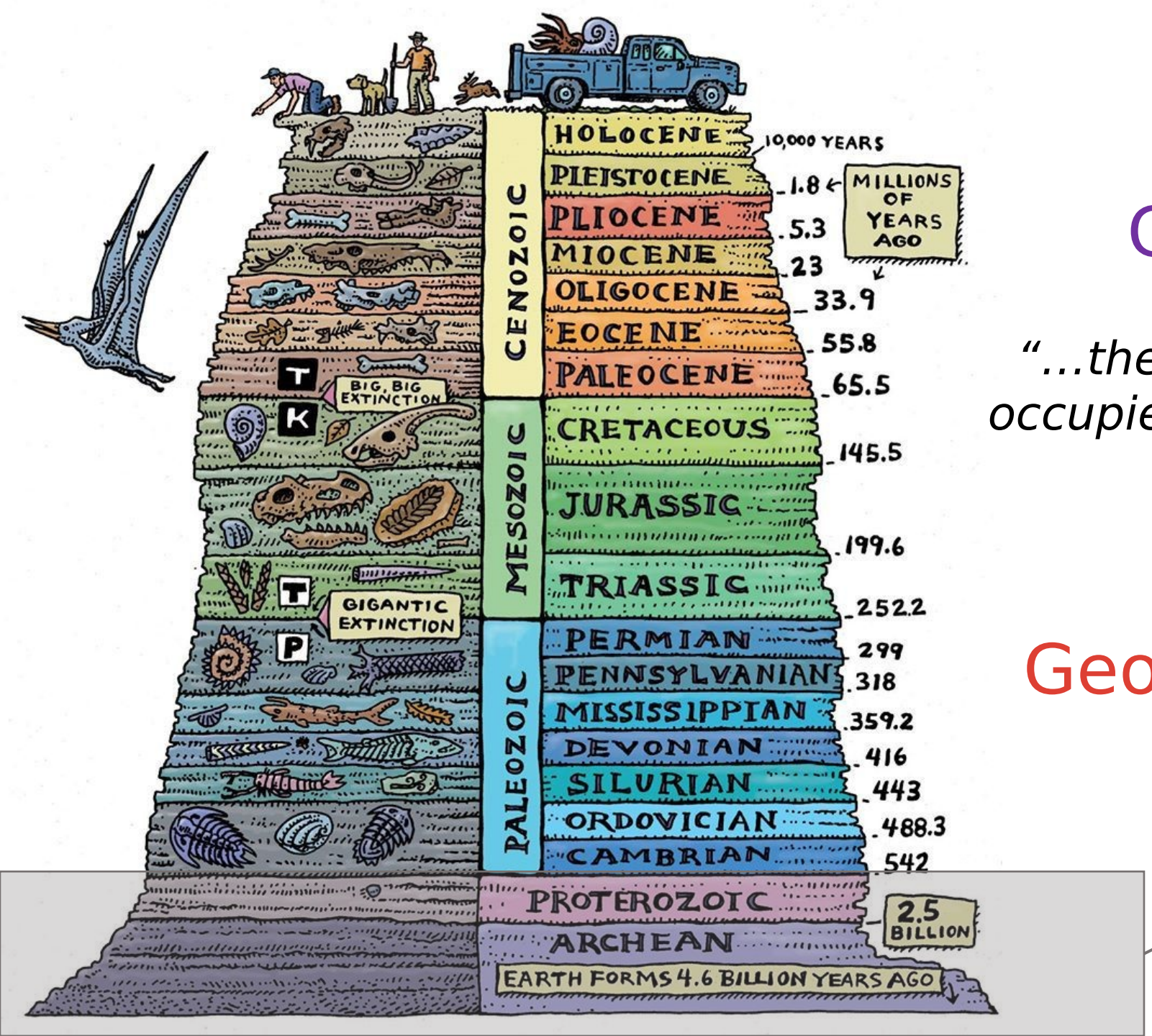
Challenges and opportunities in Astrobiology

Beyond natural sciences: humanities and social science contributions to Astrobiology

https://



Knoll & Bambach (2000)



Geological Time

"...the extensive interval of time occupied by the geologic history of Earth."
@Britannica

4.55 billion years (Ga)

Geological Time Scale

Precambrian =
Criptozoic, Azoic ou Pre-Phanerozoic

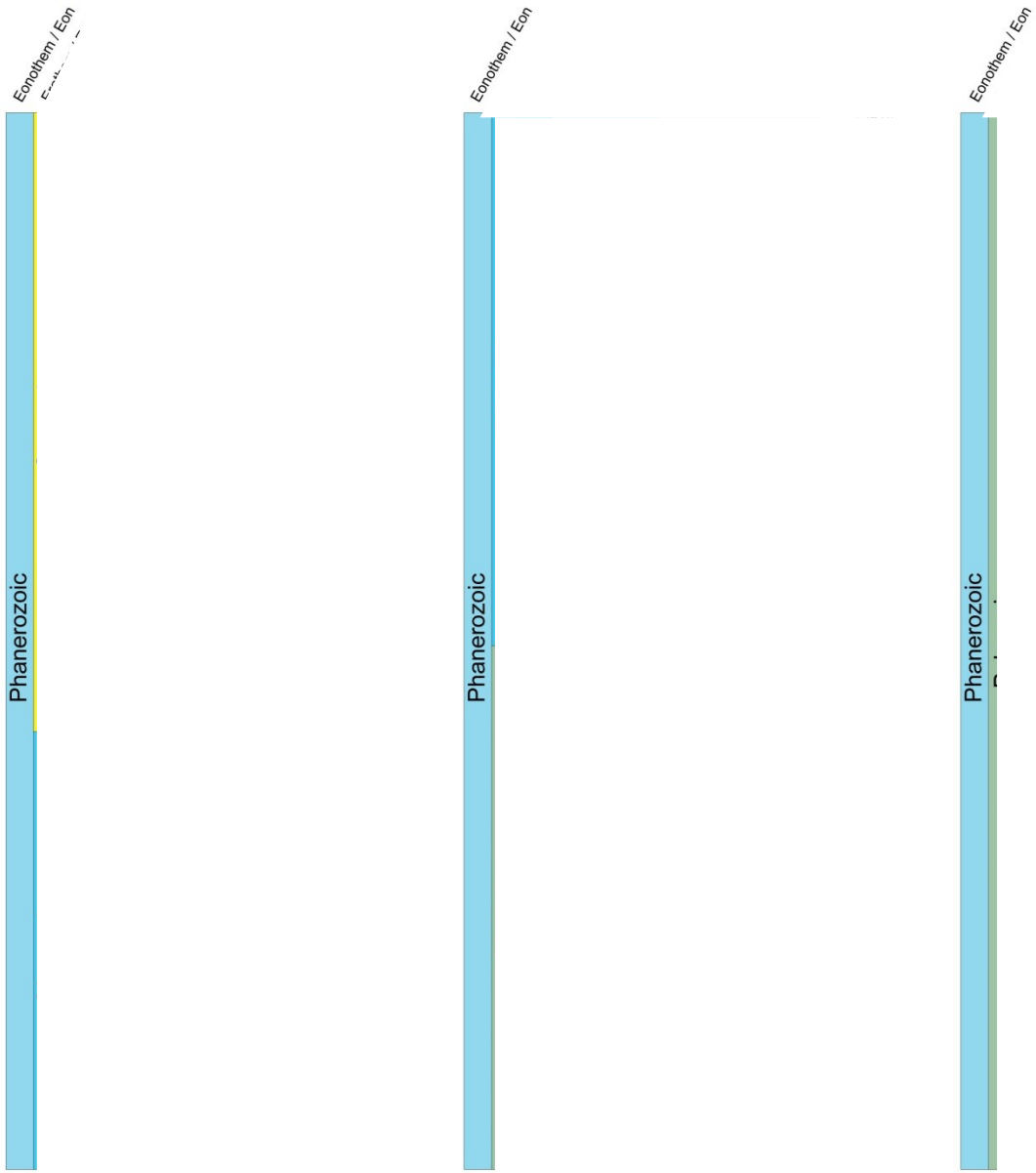
88% of Earth´s history

INTERNATIONAL CHRONOSTRATIGRAPHIC CHART

IUGS

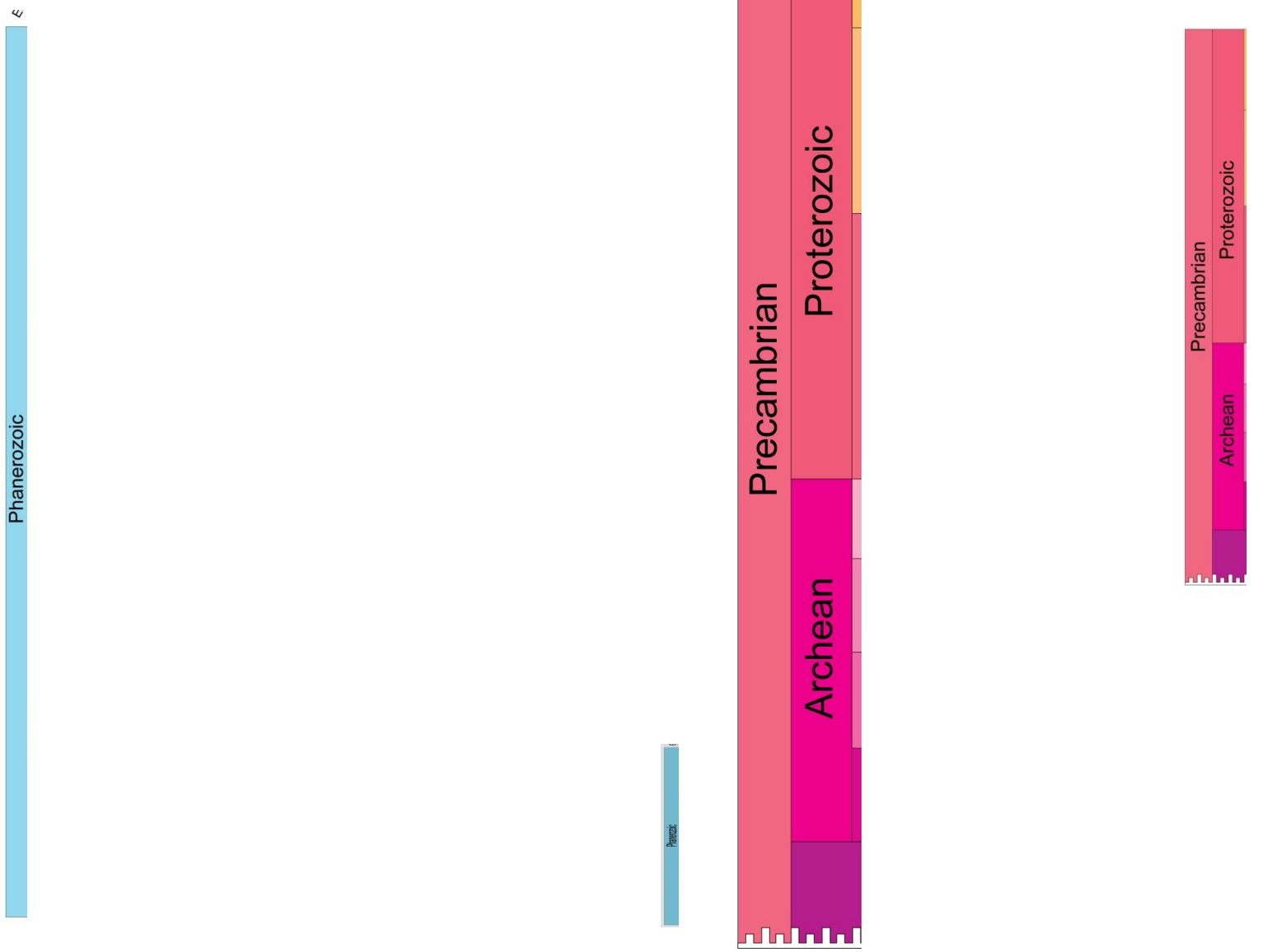
www.stratigraphy.org

International Commission on Stratigraphy

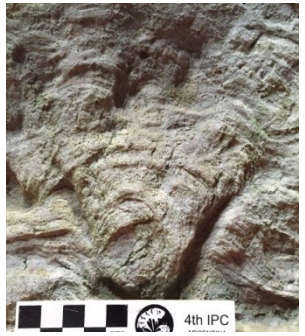


http://www.stratigraphy.org/index.php/ics-chart-timescale

Proportionally…

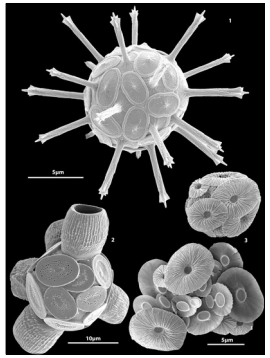


Precambrian Fossils



Microbial fossils

- **Microbialites**
- ***Microbially Induced Sedimentary Structures* (MISS)**



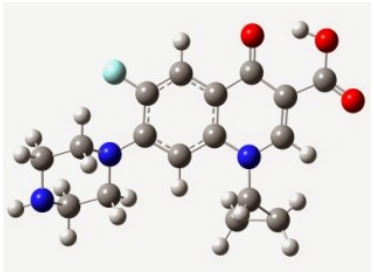
Microfossils

- **Associated to microbialites**
- **Free cells - planctonics or benthonic**
- **Eukaryotes and prokaryotes**

Precambrian Fossils

Macrofossils

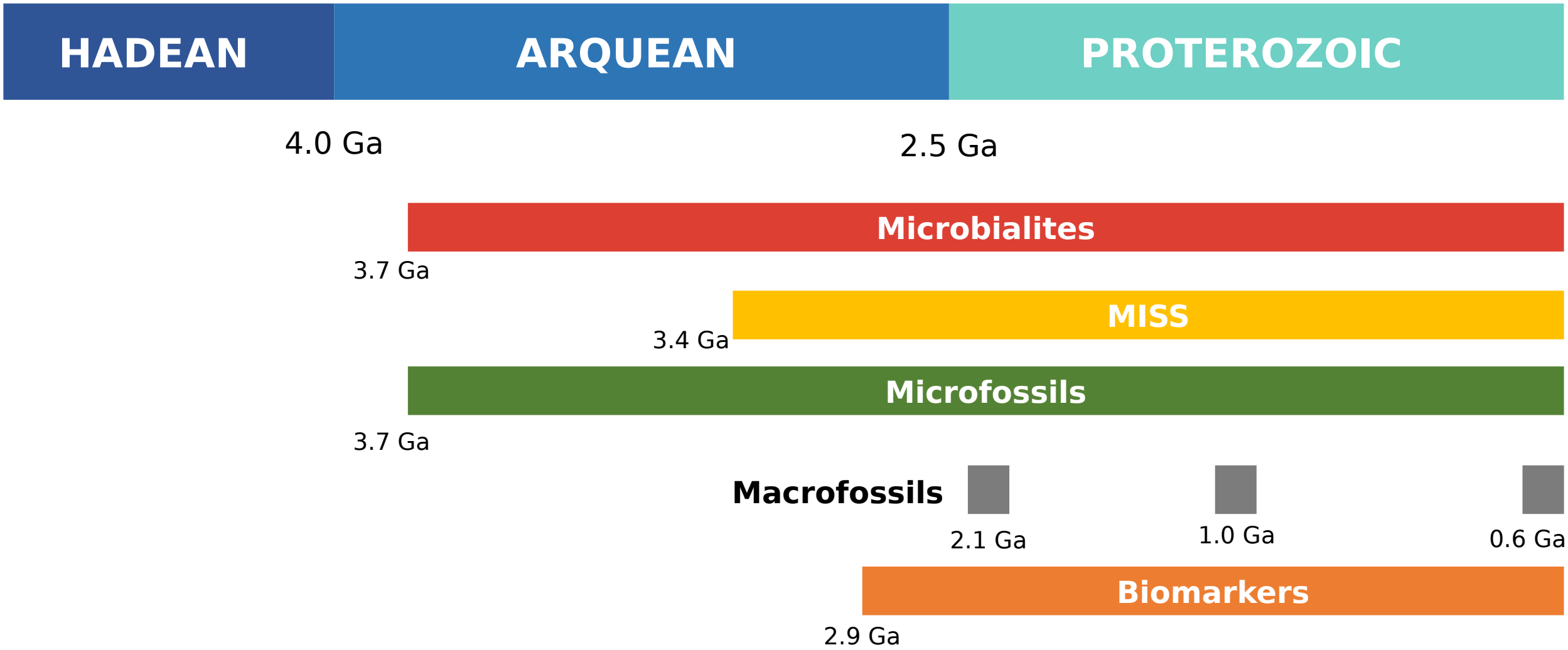
- **Metazoans**
- **Rangeomorphs e Erniettomorphs**
- **Algae**
- **Incertae Sedis**



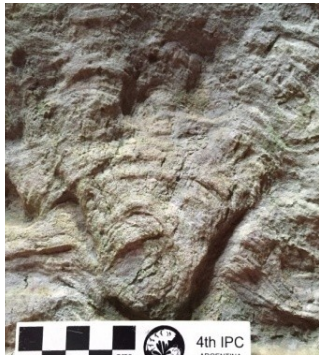
Biomarkers

- **Organic matter and molecules**
- **Isotopes**

Precambrian Fossils

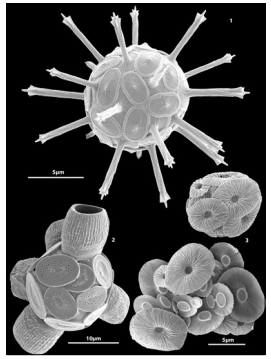


Precambrian Fossils



Microbialites

MISS



Microfossils

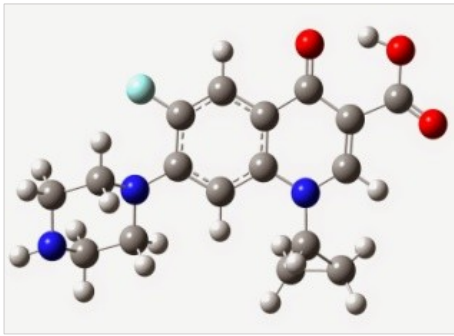
Metazoans

Rangeomorphs

Erniettomorphs

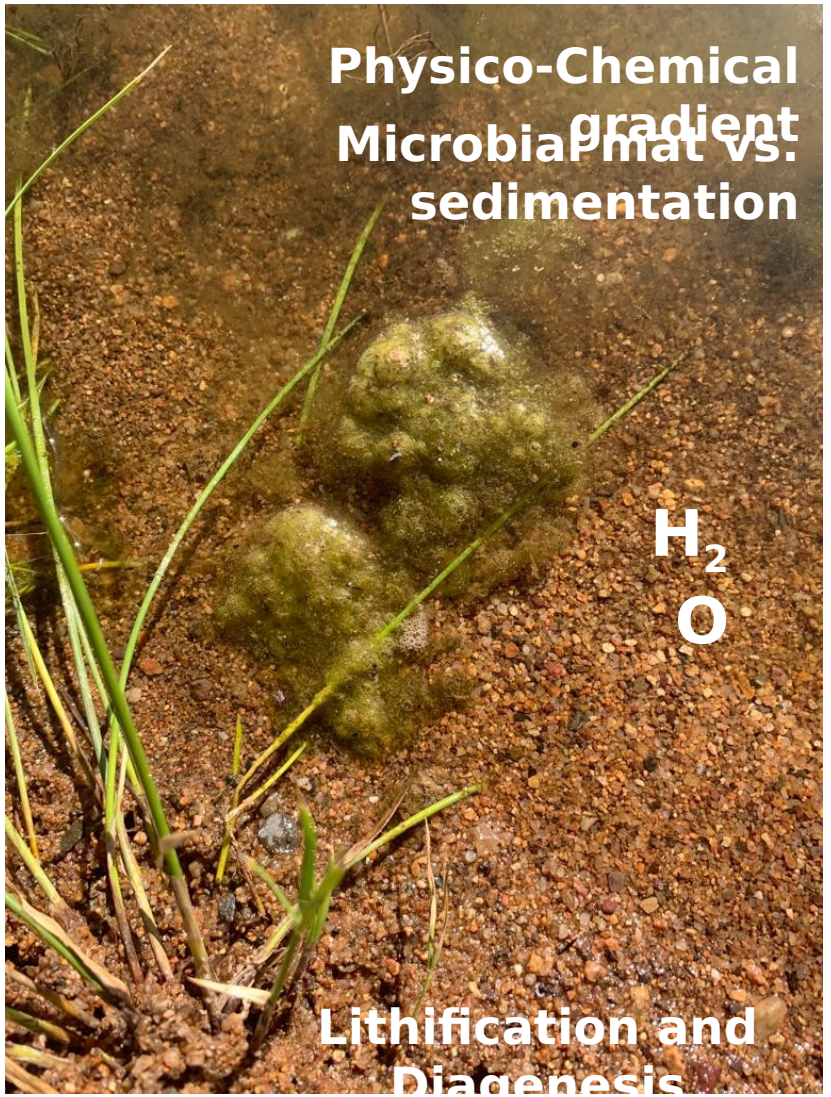
Algae

Incertae Sedis

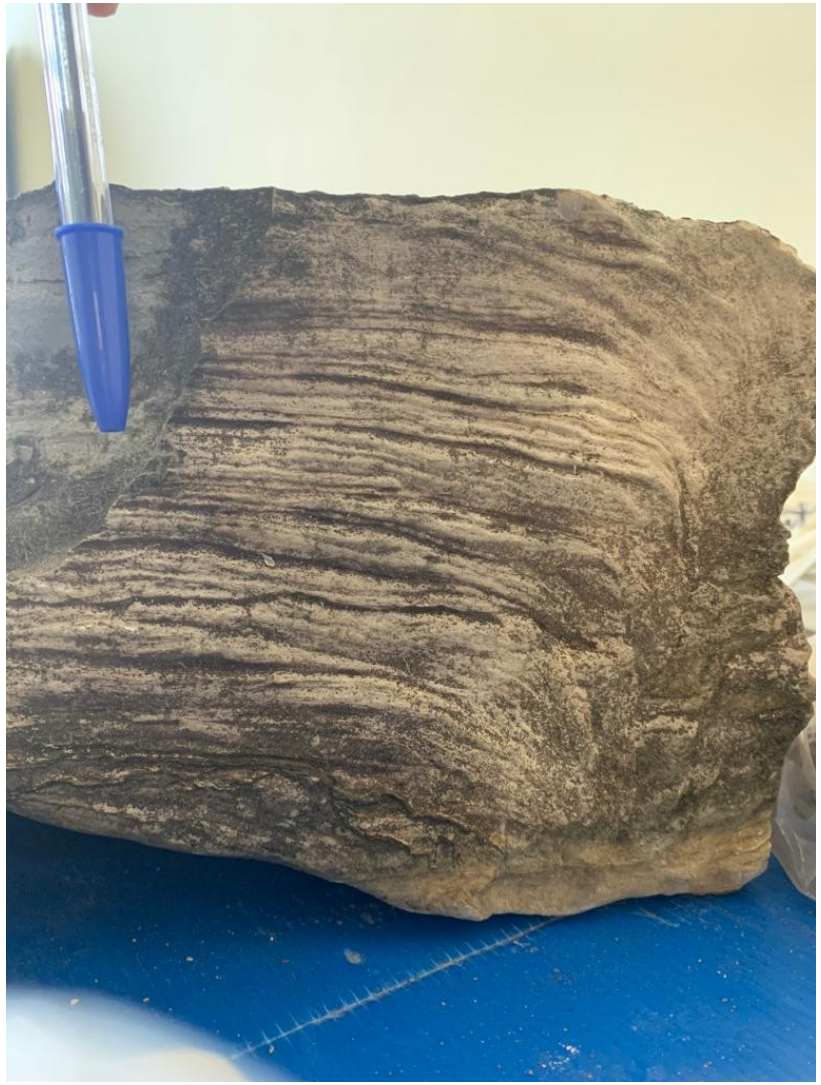


Biomarkers

Microbialites - Stromatolites



Microbialites - Stromatolites

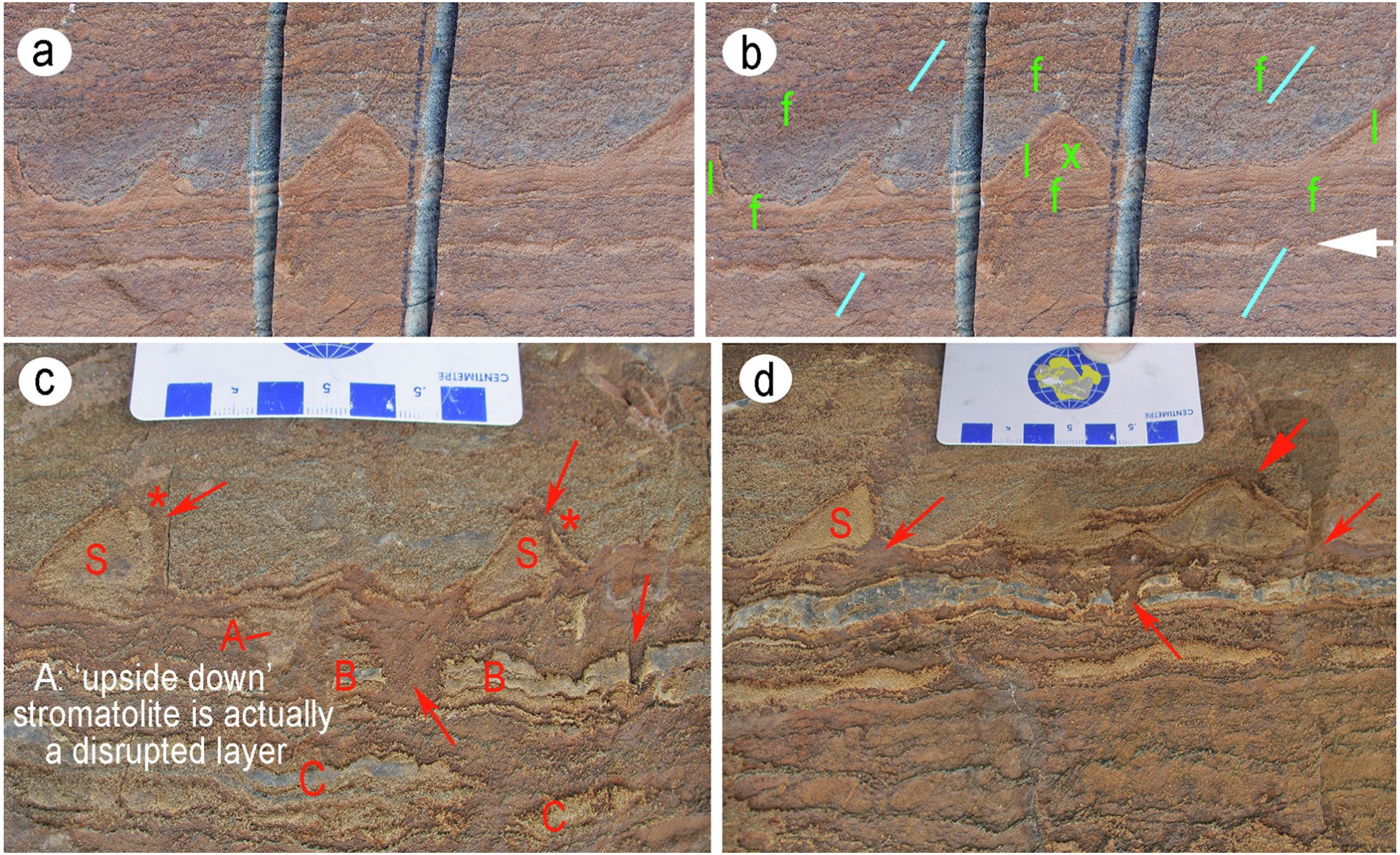


Una Group
Ediacaran–Cambrian

Microbialites - Stromatolites

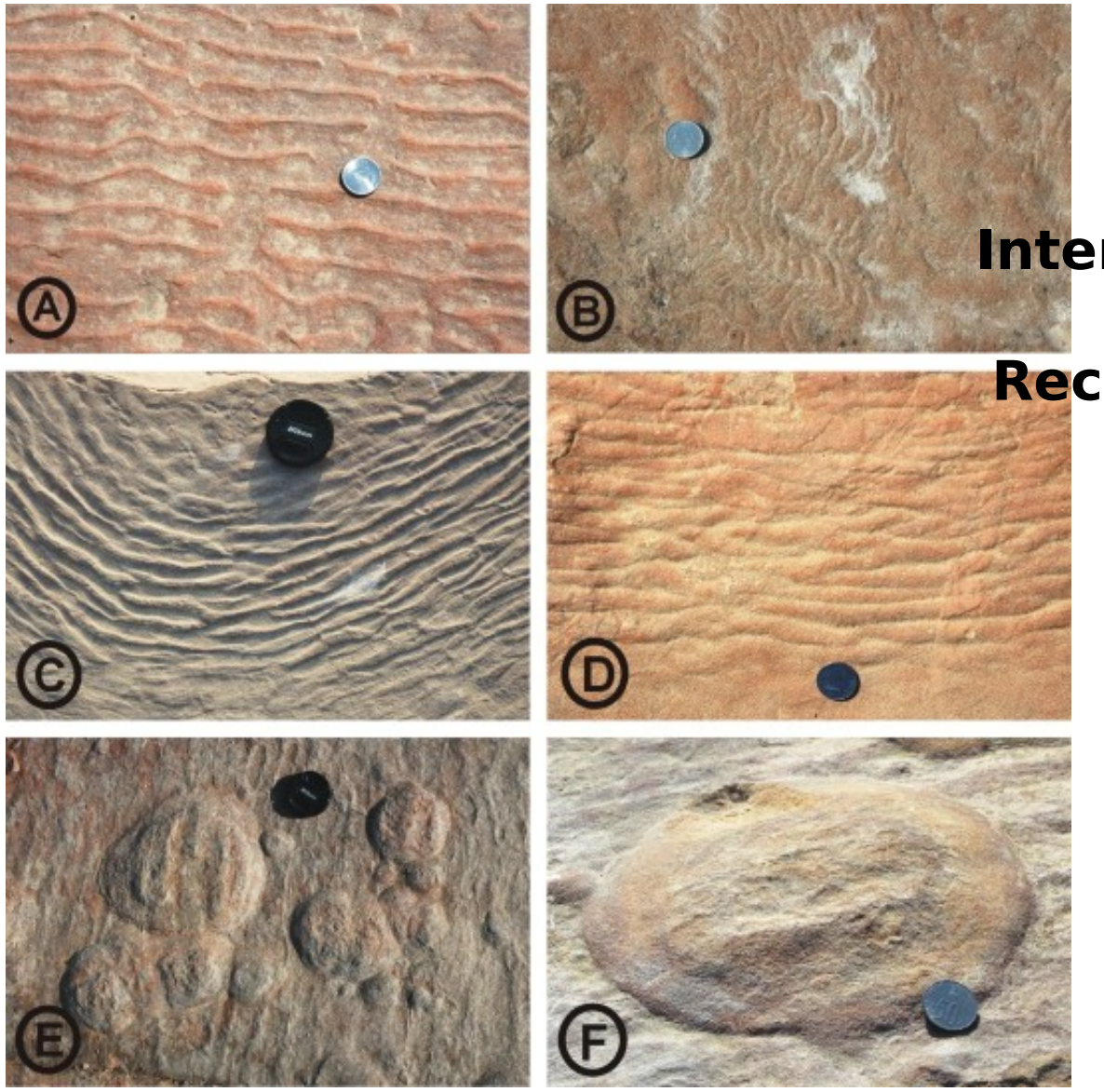
Warrawoona Group
Paleoarchean,

Microbialites - Stromatolites



Isua Supergroup
Paleoarchean, Greenland

Microbially Induced Sedimentary Structures



Kumar & Ahmad (2014)

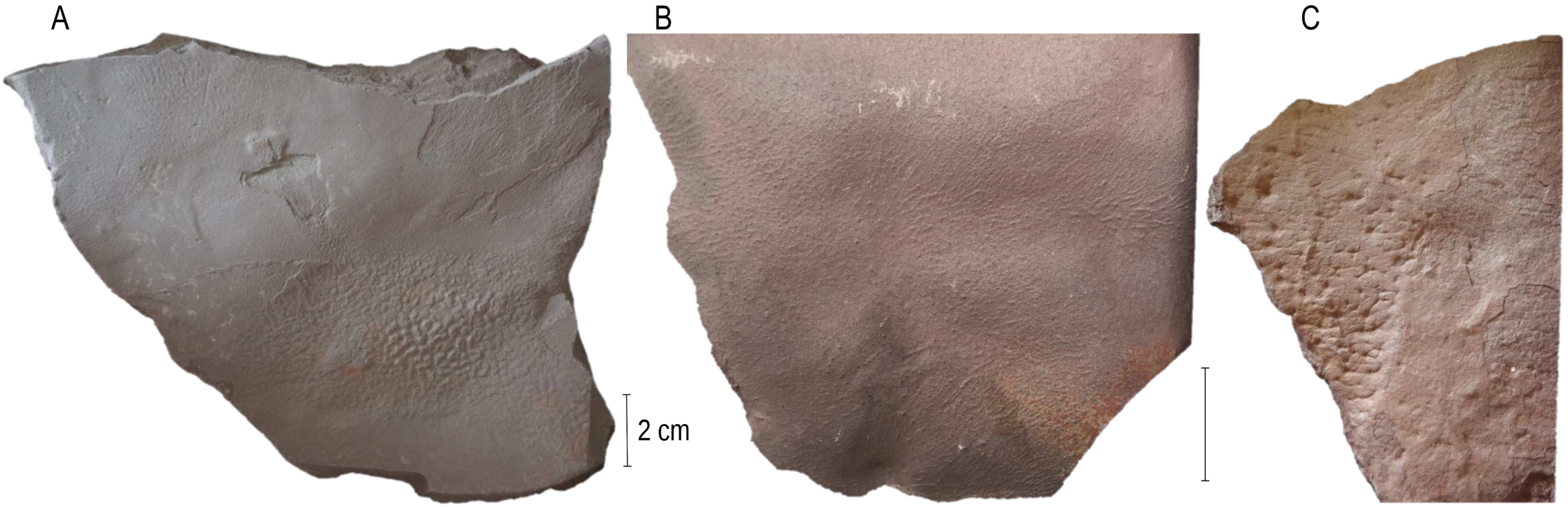
Interaction microorganisms and sediments

Record of life in siliciclastic environments

17 types of MISS

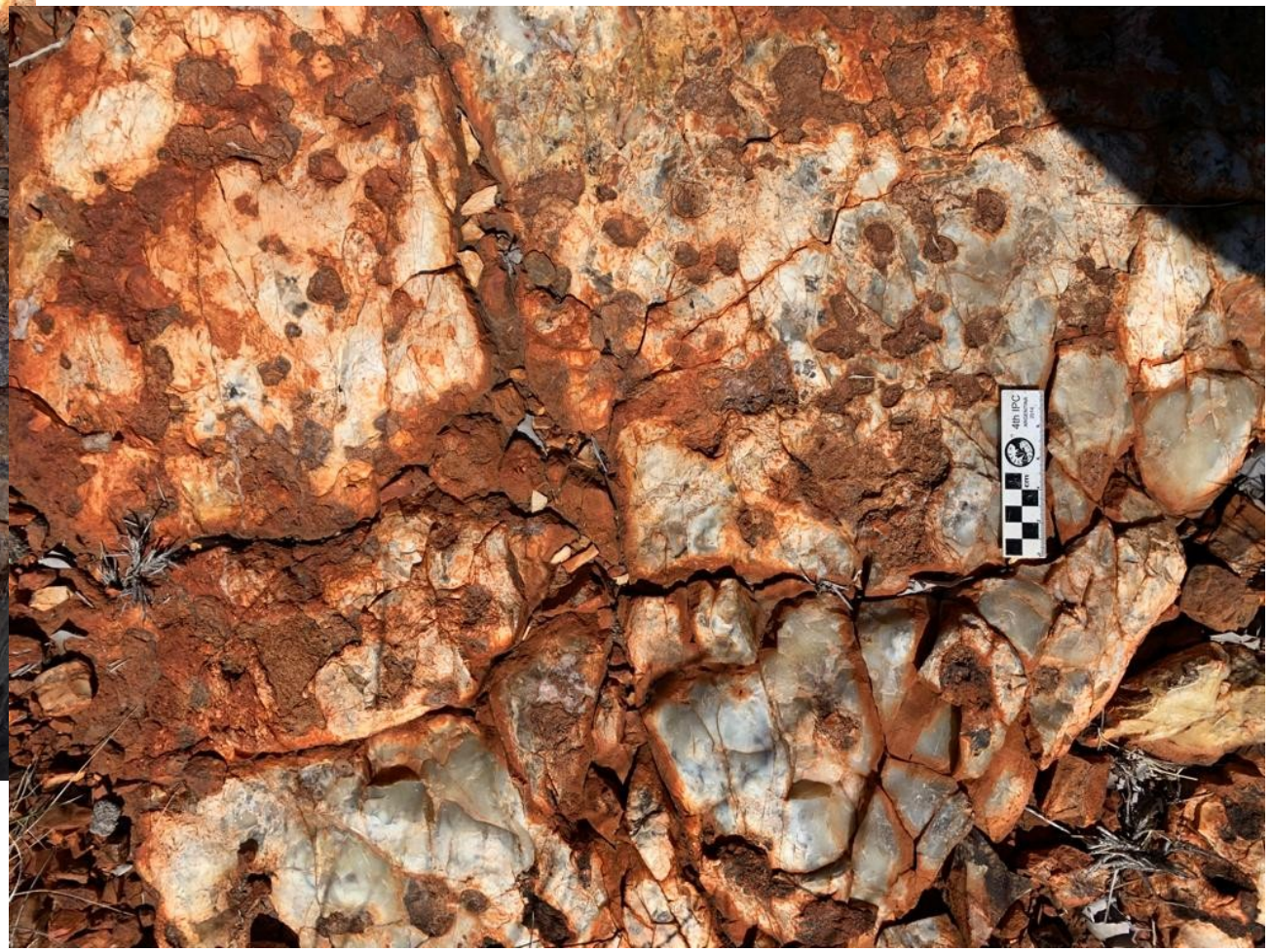
3.4 Ga to Recent

Microbially Induced Sedimentary Structures

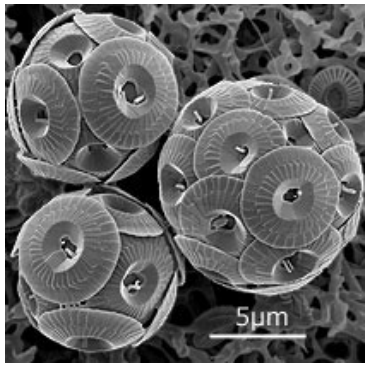


MISS – Bambuí Group
Ediacaran–Cambrian

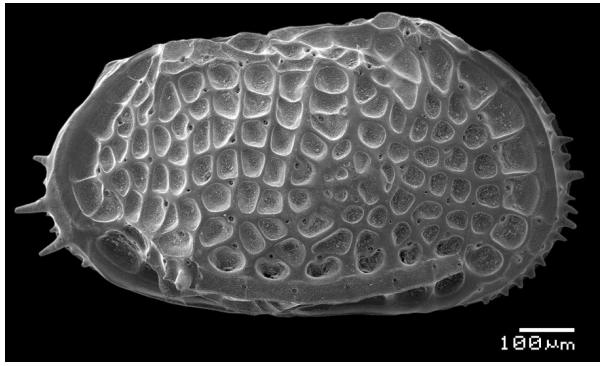
Microbially Induced Sedimentary Structures



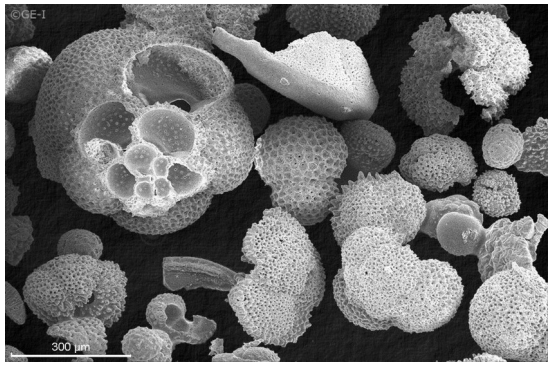
Warrawoona Group
Paleoarchean, Australia



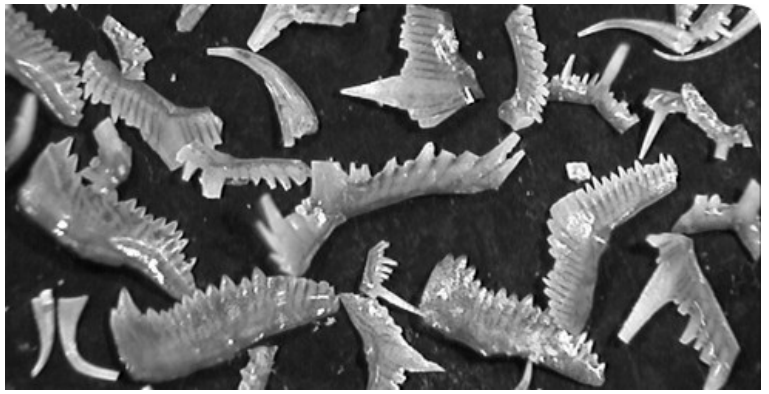
Cocolitóforos



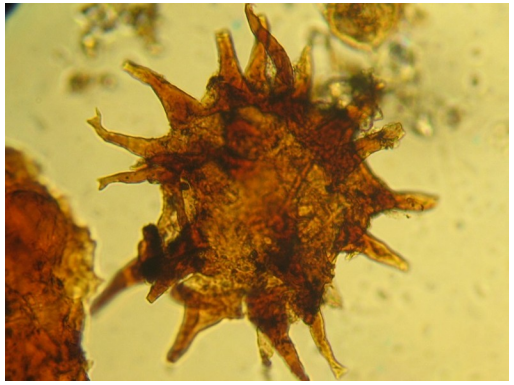
Ostracodes



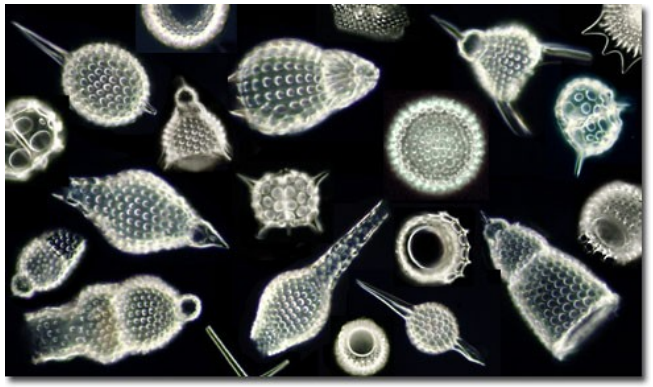
Foraminíferos



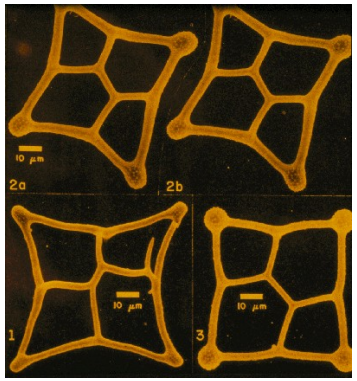
Conodontes



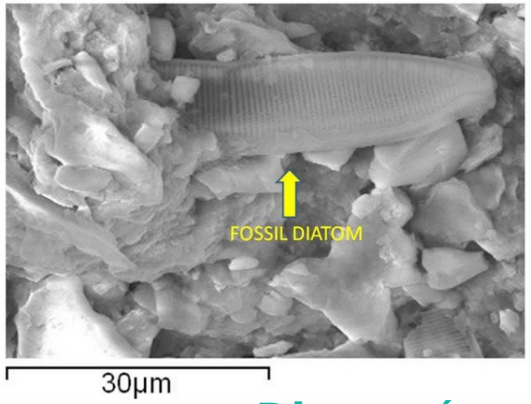
Acritarcos



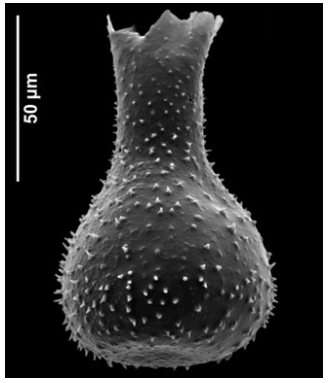
Radiolários



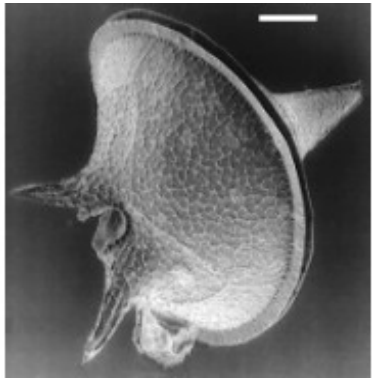
Silicoflagelados



Diatomáceas

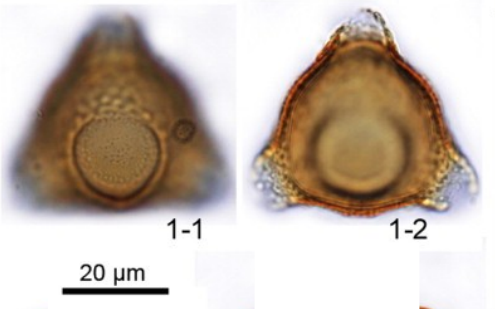


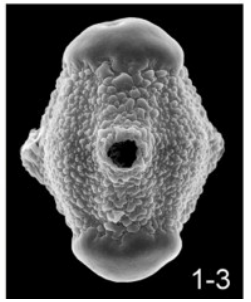
Quitinozoários



Dinoflagelados

Esporos



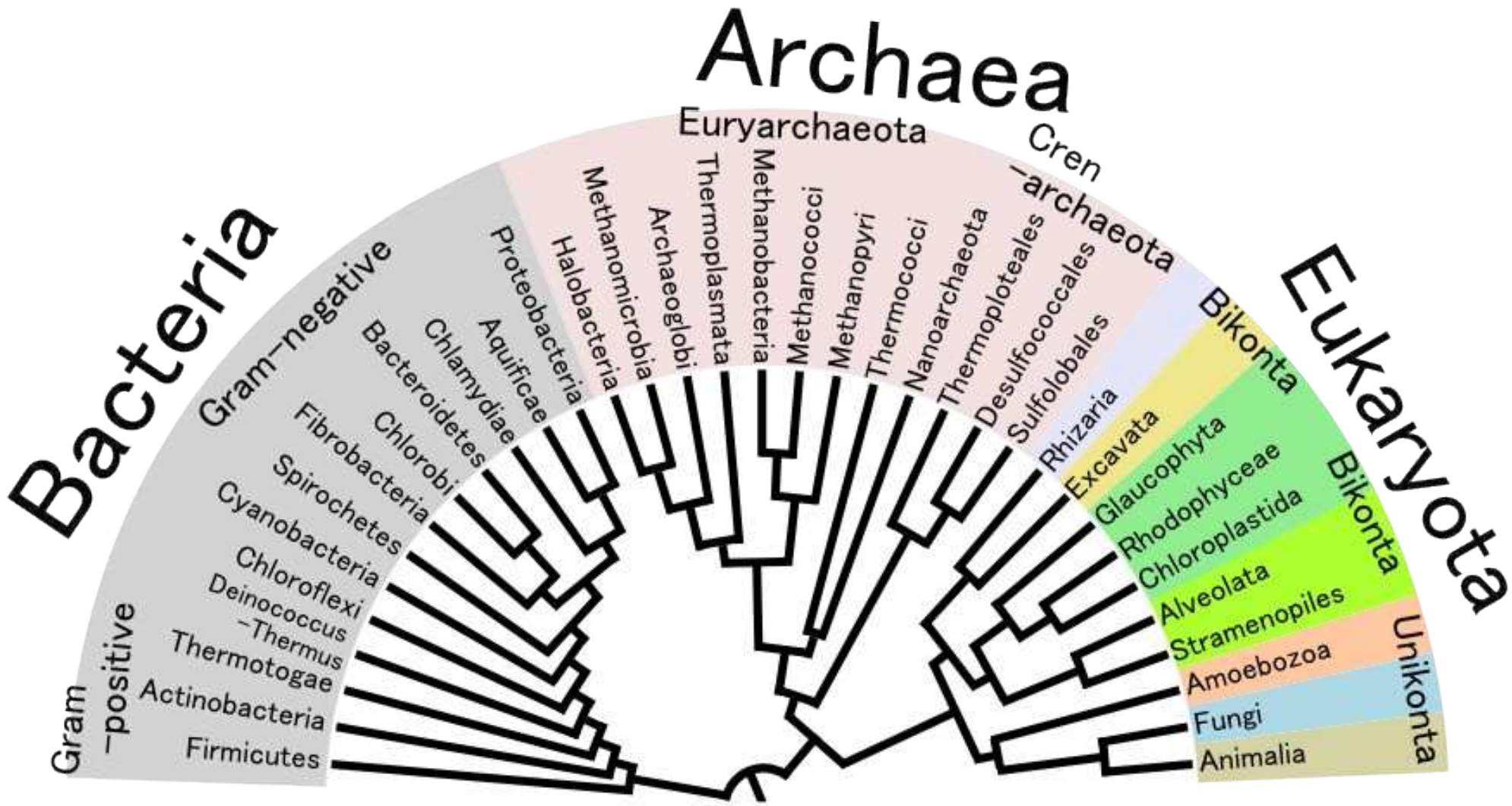


Mao et al. (2012)

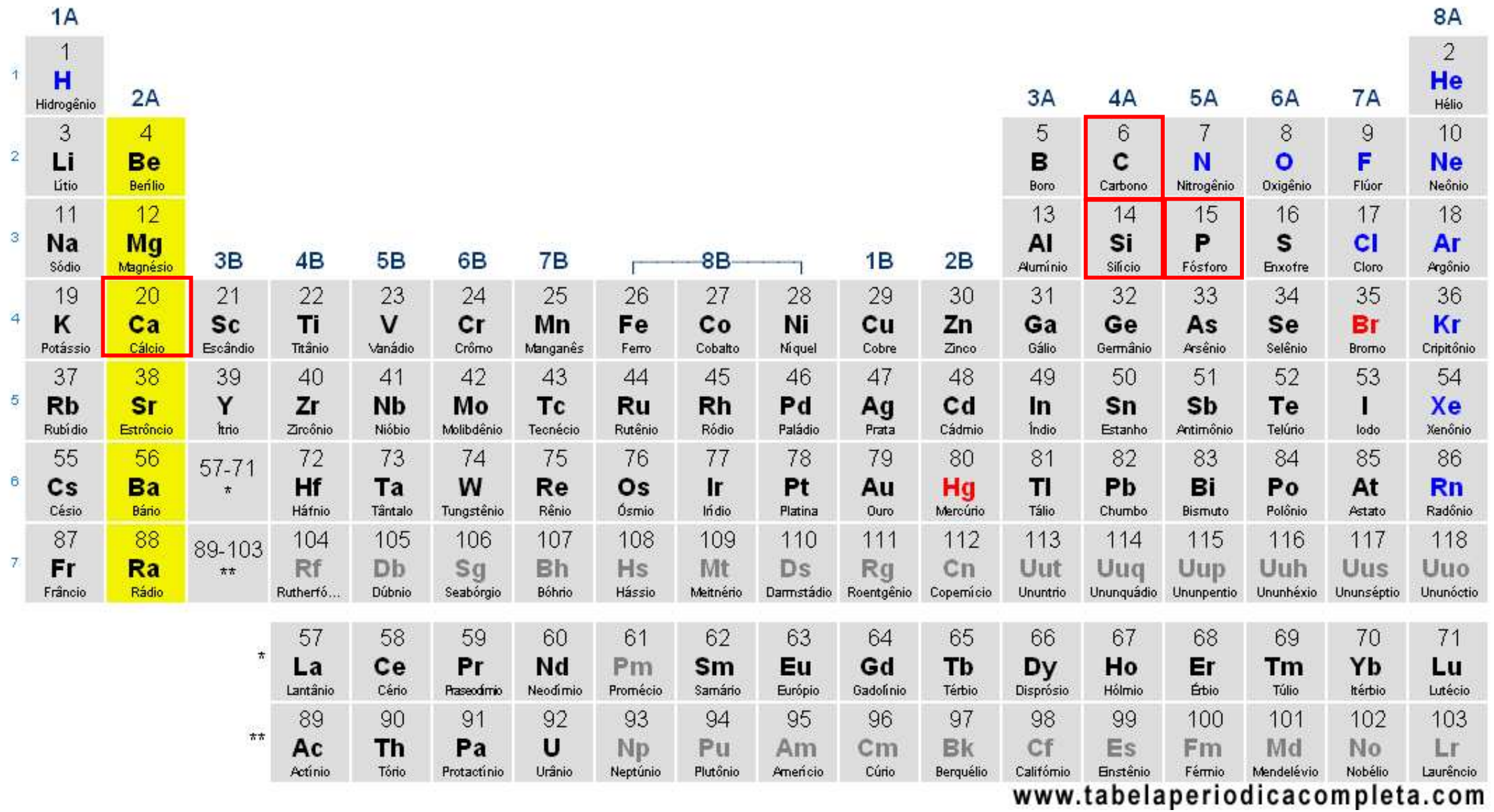
Pólen

Imagens da Internet

How to classify them?



Haq & Boersma (1994)

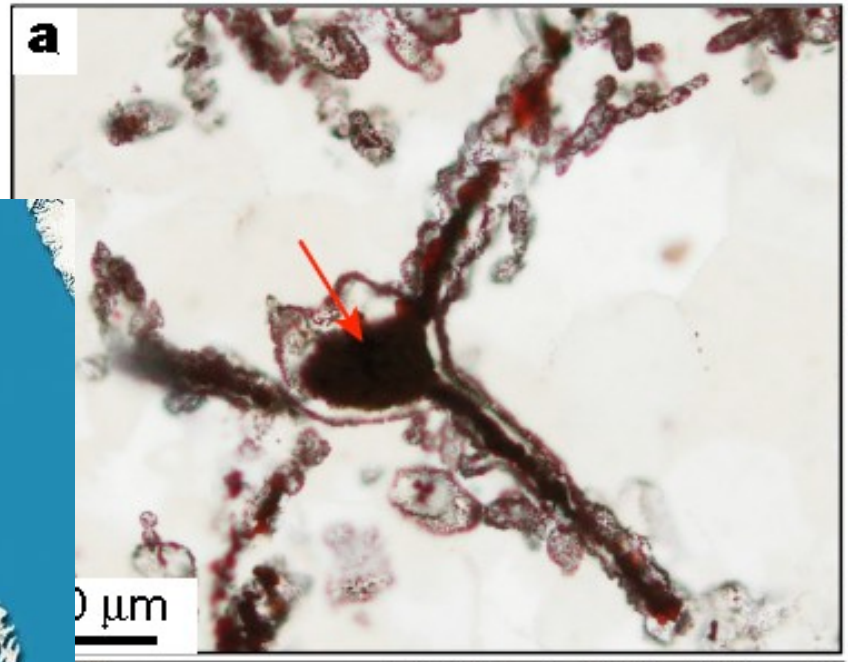


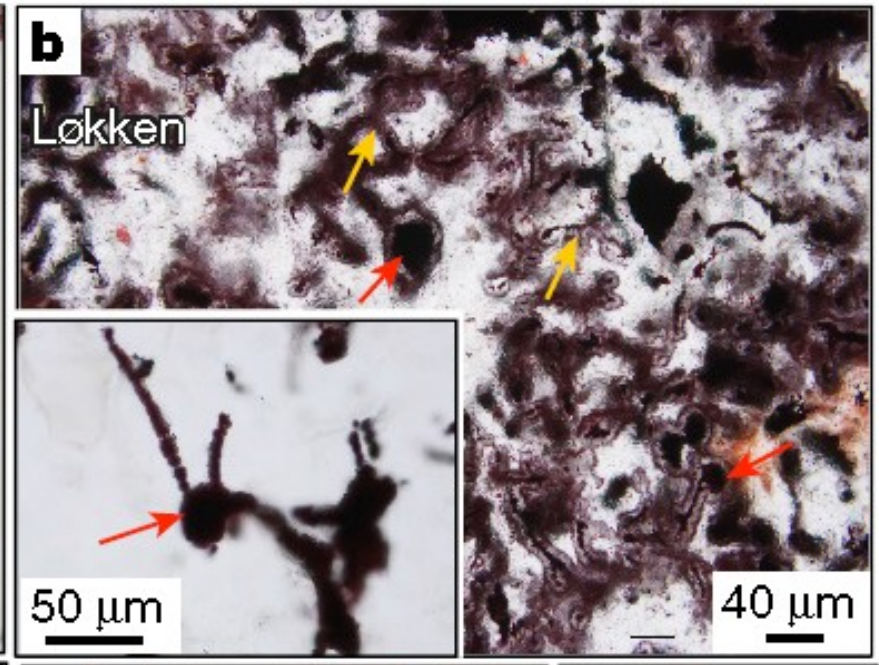
Oldest microfossils

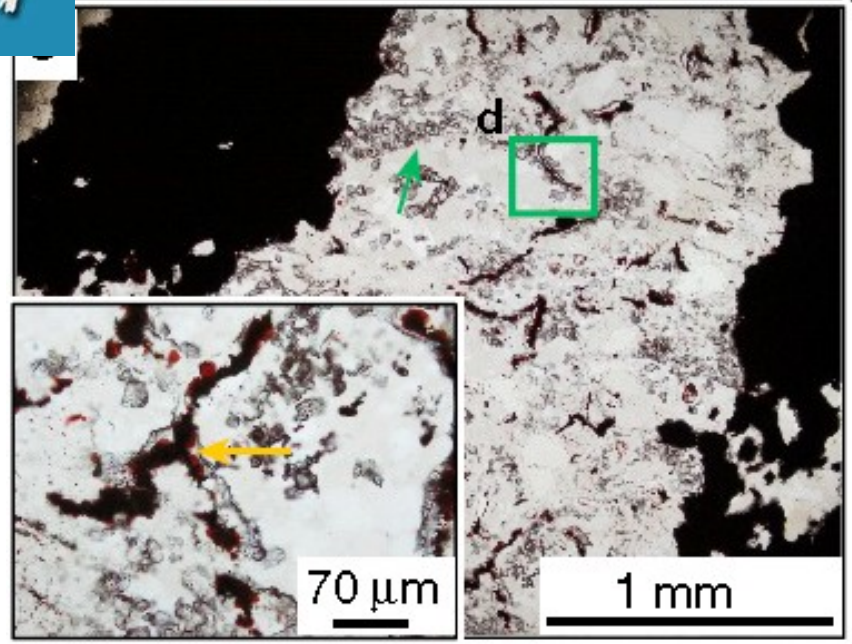
Dood et al. (2017)

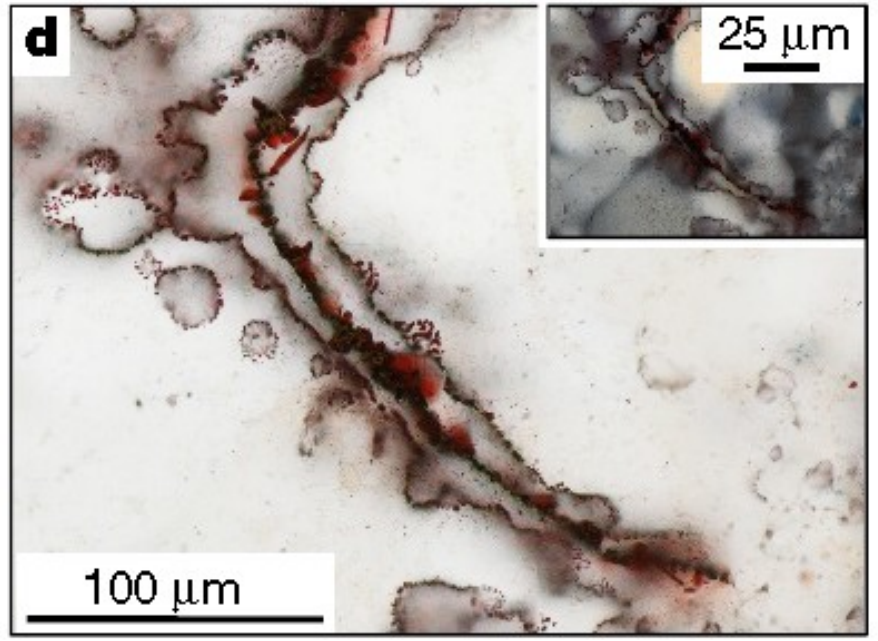
3.7 Ga
Quebec, Canada

Banded Iron Formation





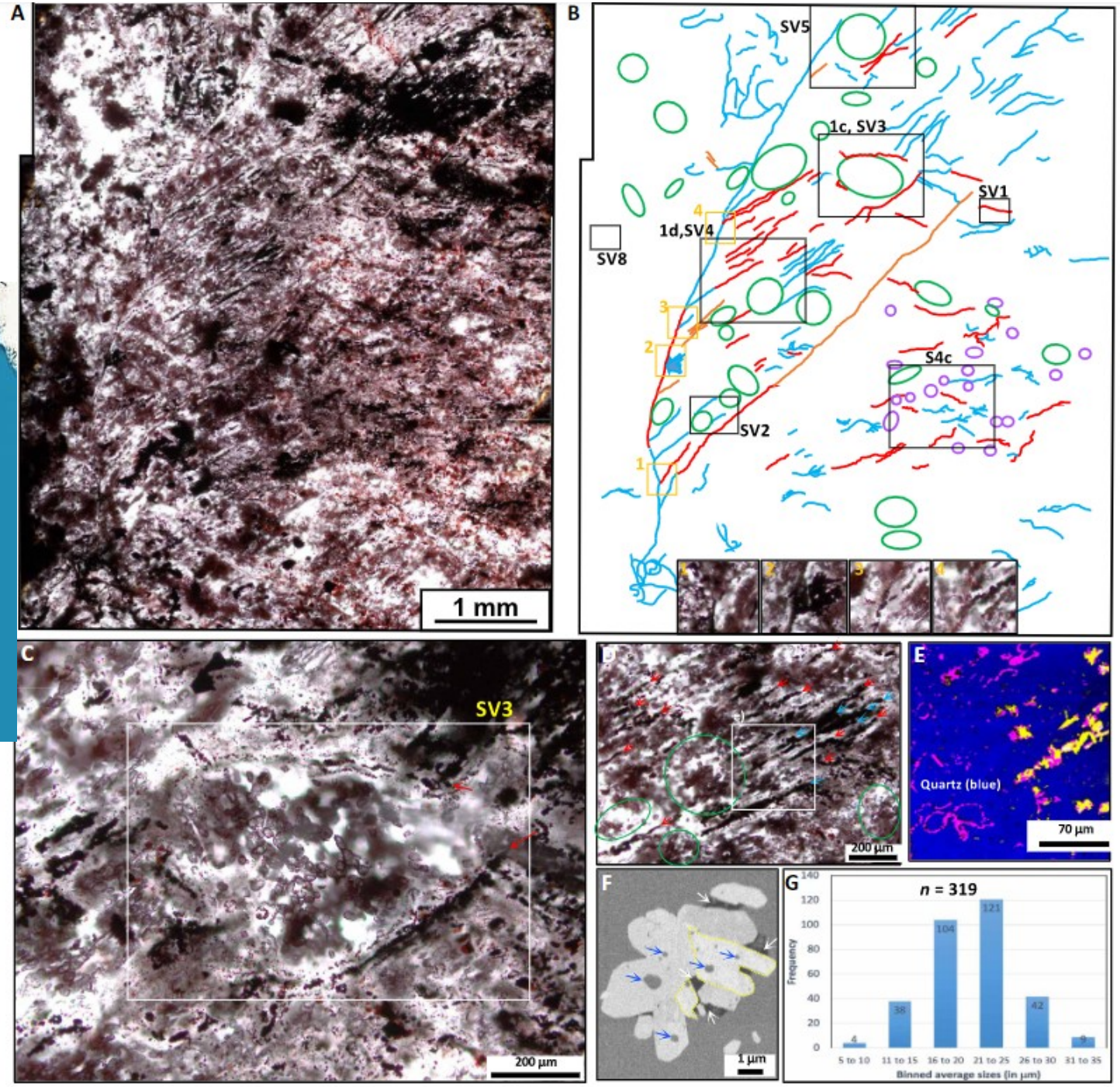




Oldest microfossils

4.2 Ga
Quebec, Canada

Banded Iron Formation



Bineau et al. (2022). Science.

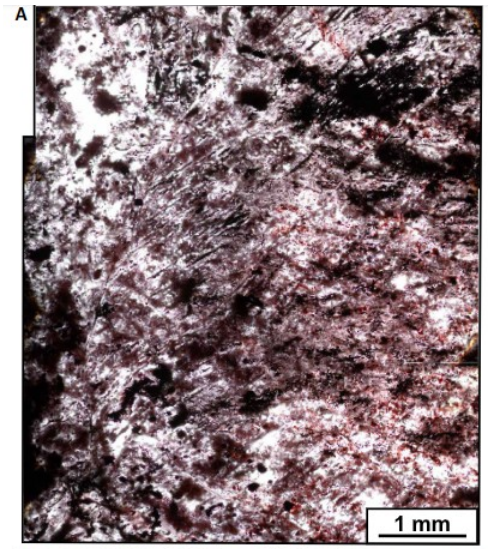
C

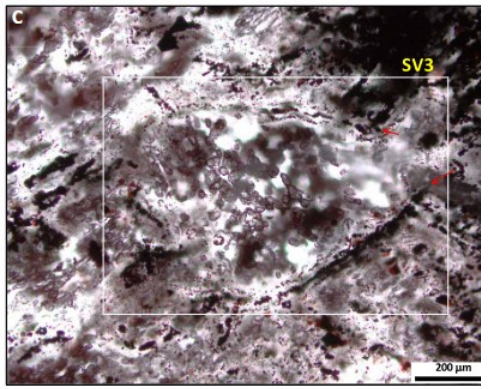
EARTH

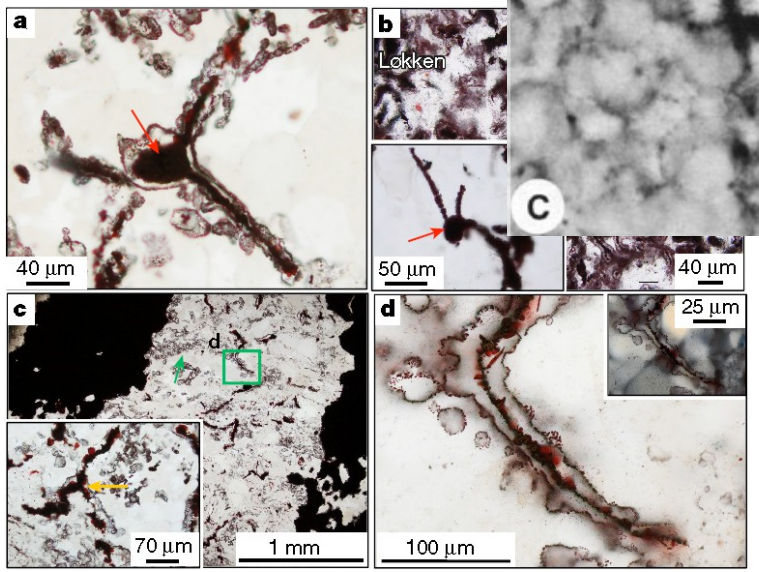
Hadean	Archeaen	Proterozoic	Phanerozoic

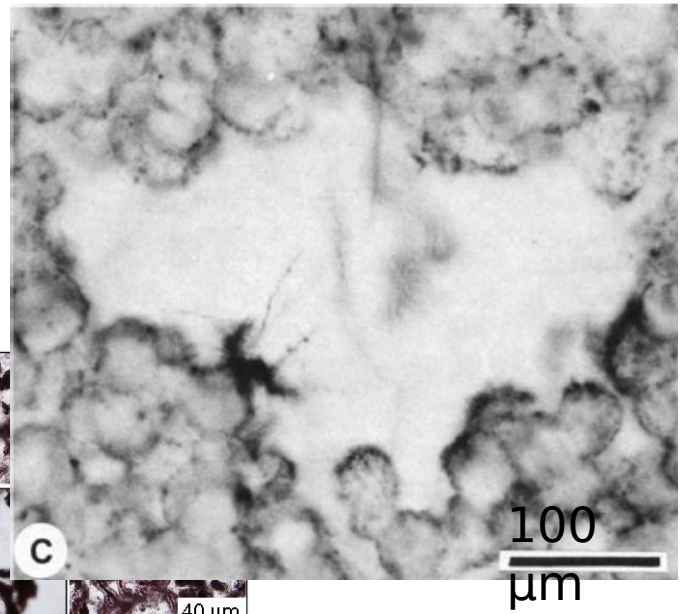
4.55 Ga 4.2 Ga 4.0 Ga 3.7 Ga 3.4 Ga 2.5 Ga 0.5 Ga

Ca, Si, P

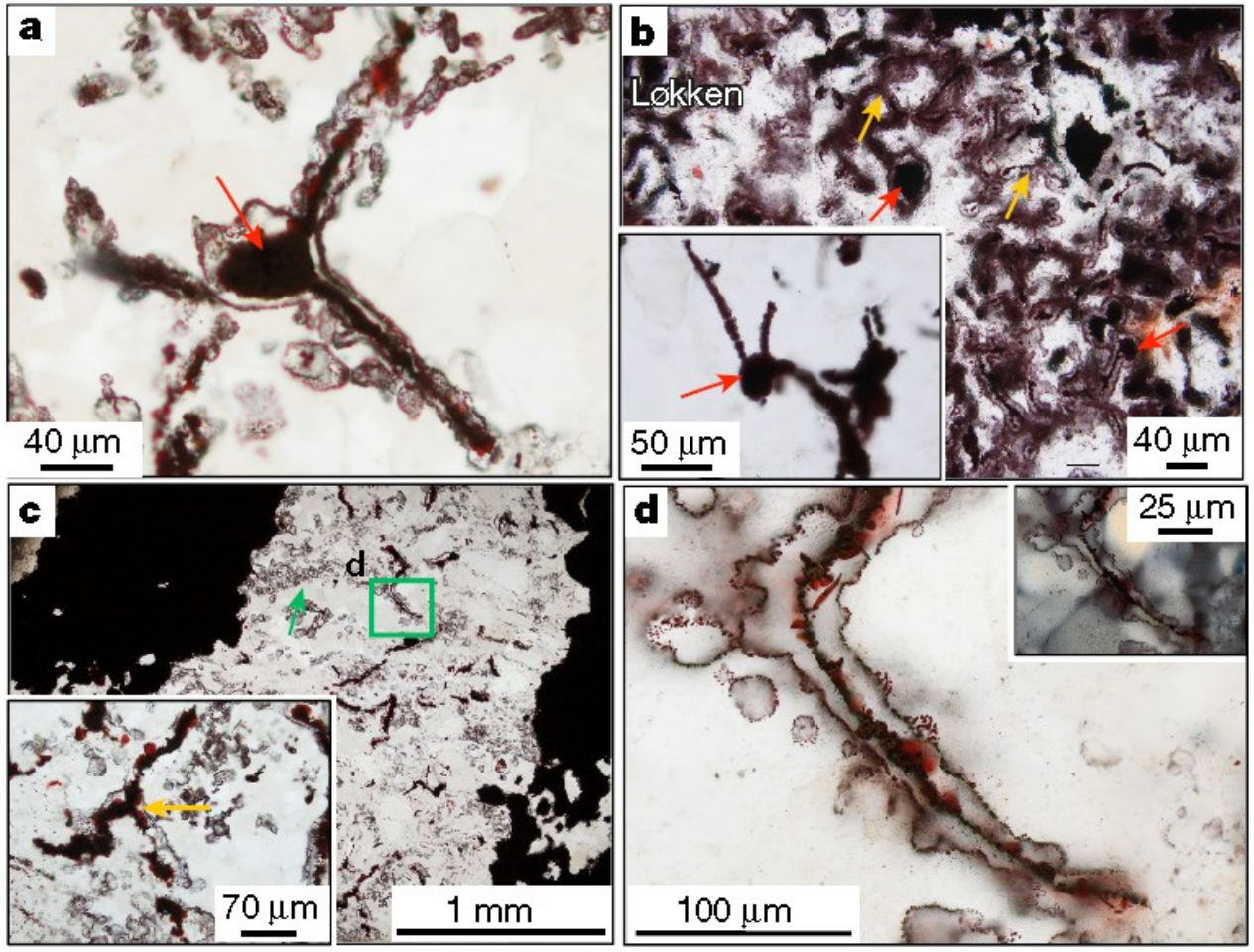


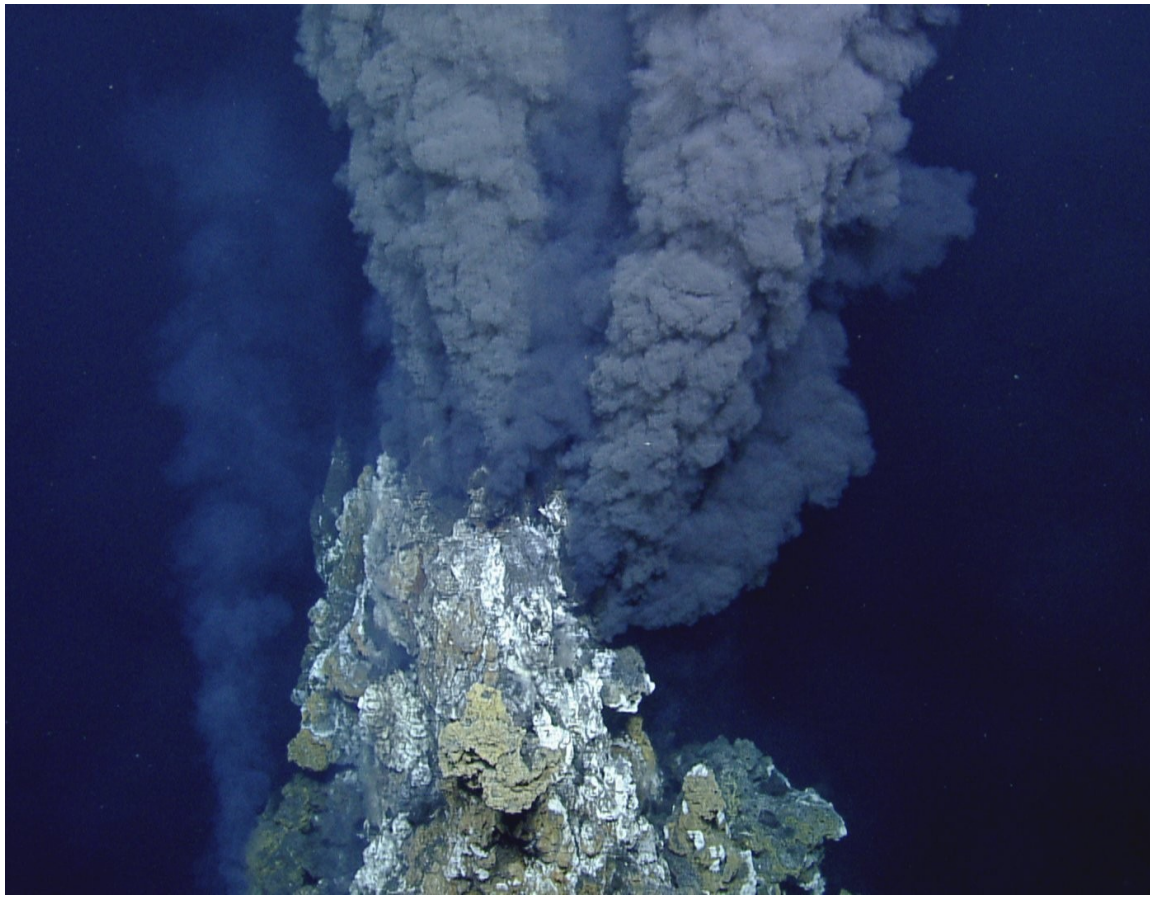






Biological affinity?
Modern analougues





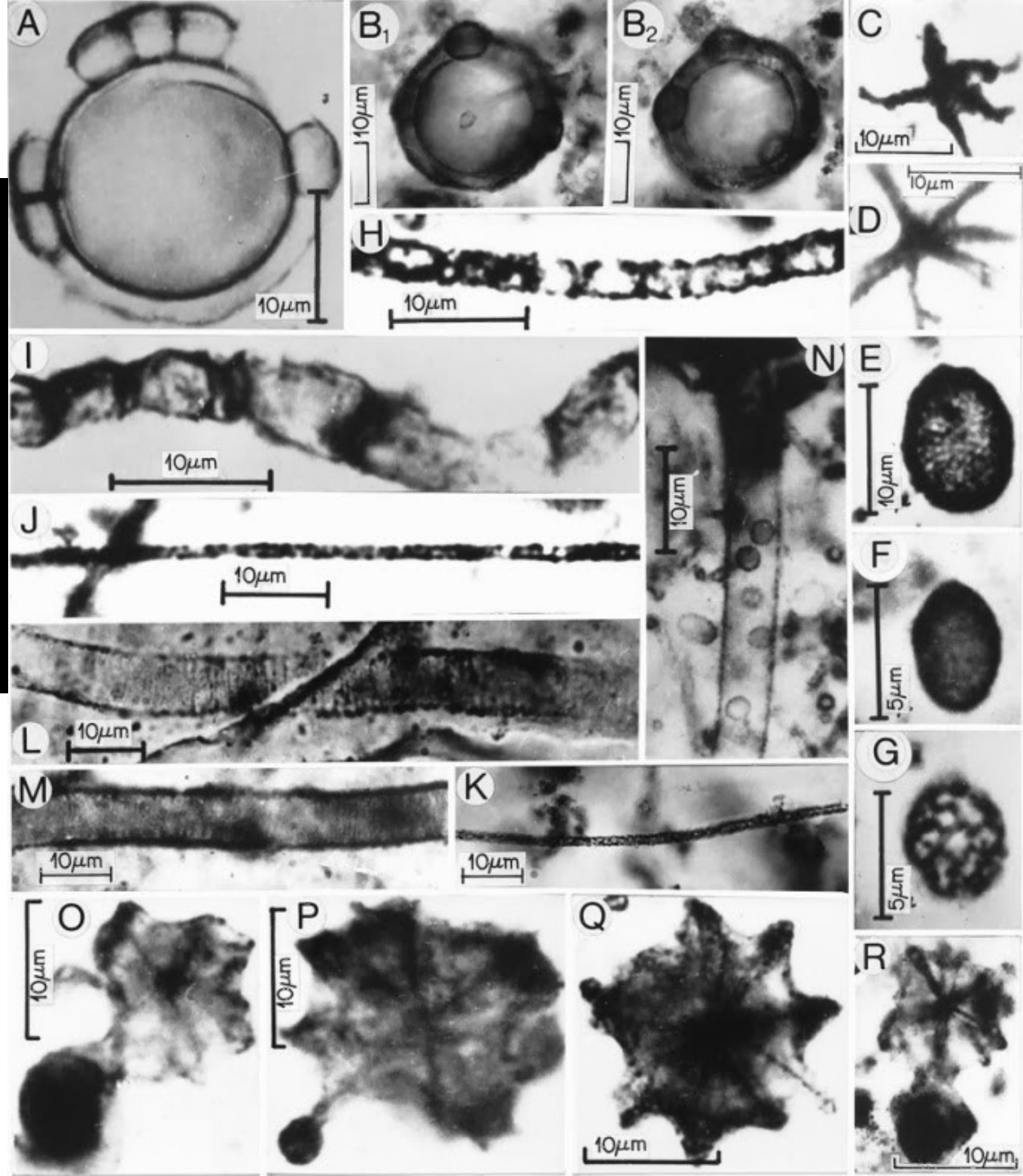
Biota de Gunflint

Subtidal setting

Associated to BIFs

16 taxa

6 txs of uncertain affinity



www.nature.com/scientificreports

SCIENTIFIC REPORTS

nature research

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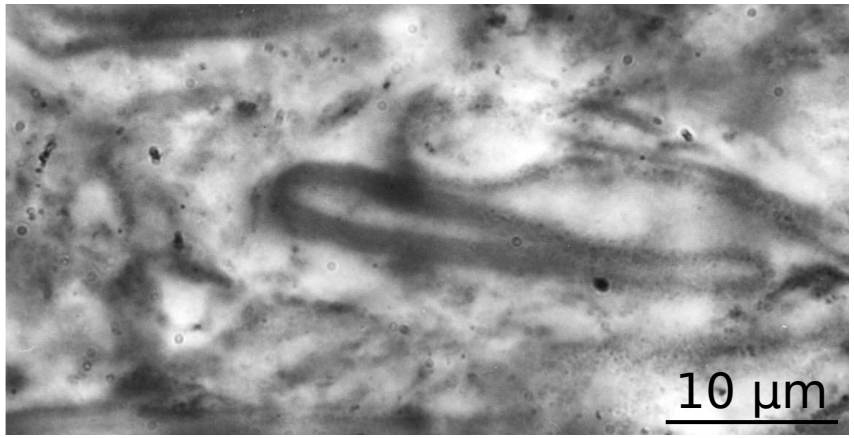
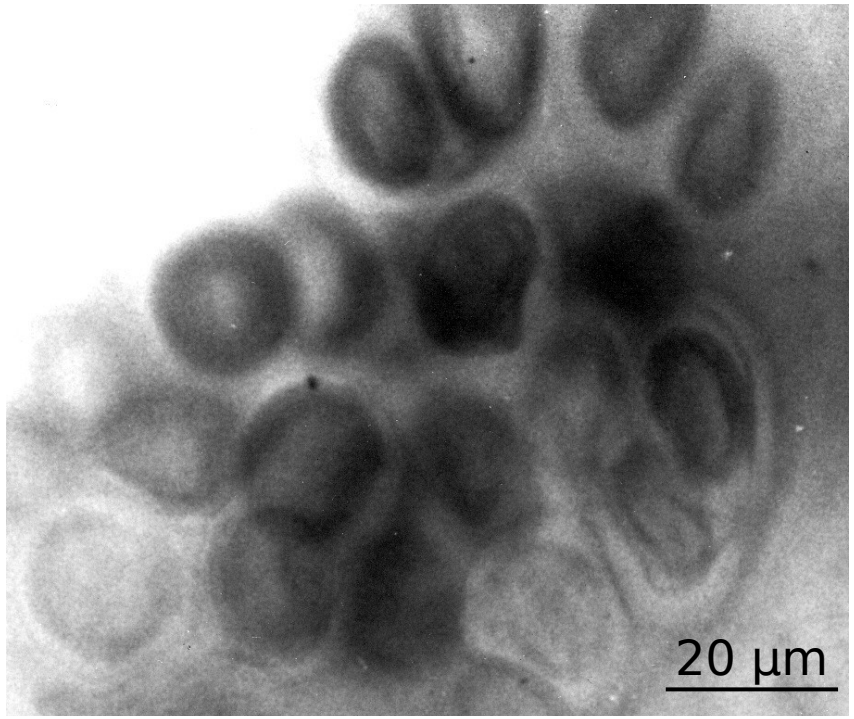
OPEN

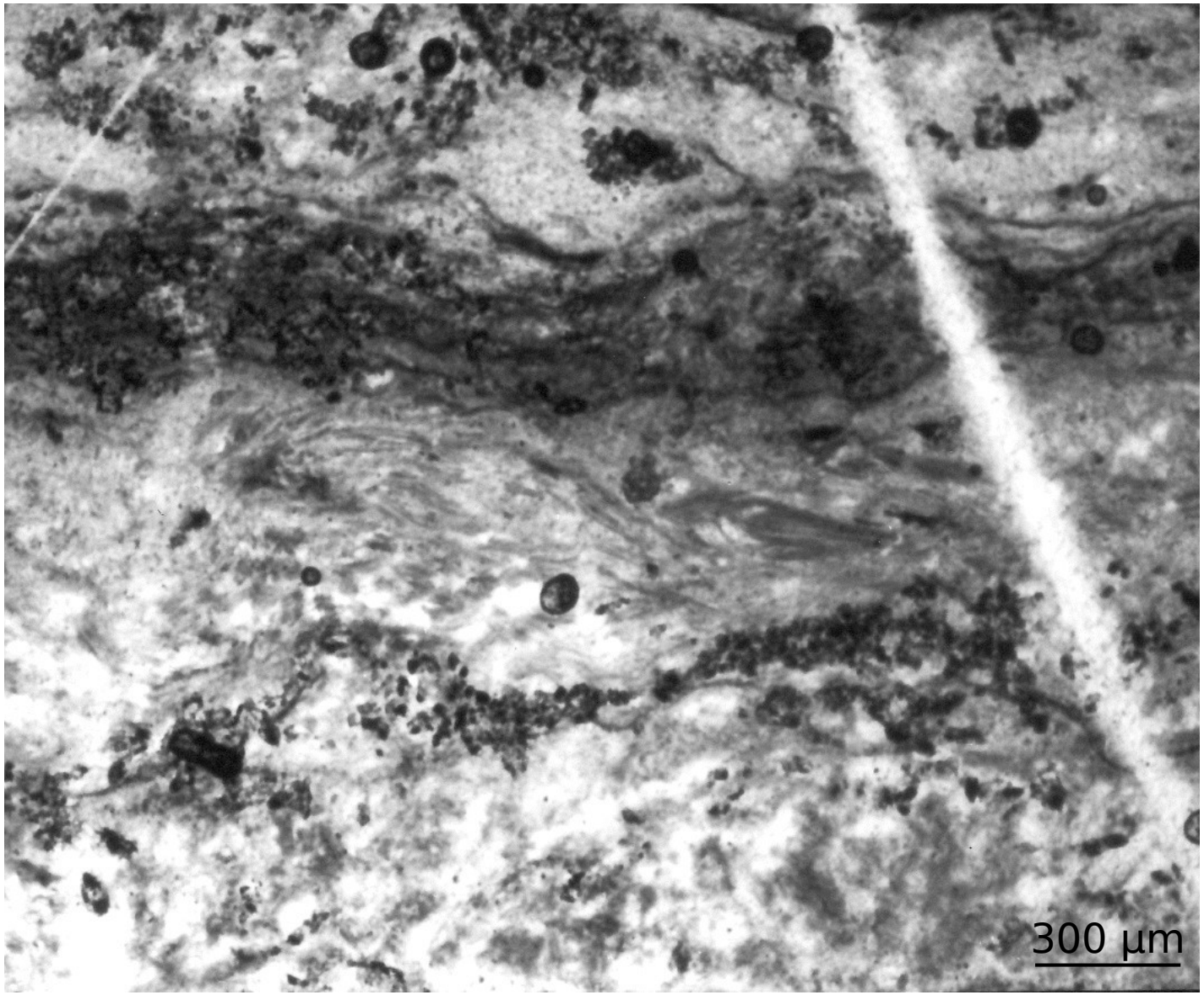
Nanoscale 3D quantitative imaging of 1.88 Ga Gunflint microfossils reveals novel insights into taphonomic and biogenic characters

L. Maldanis[1,2,11] ✉, K. Hickman-Lewis[3,4], M. Verezhak[5], P. Gueriau[6,12], M. Guizar-Sicairos[5], P. Jaqueto[7], R. I. F. Trindade[7], A. L. Rossi[8], F. Berenguer[9], F. Westall[3], L. Bertrand[6,10] & D. Galante[1]

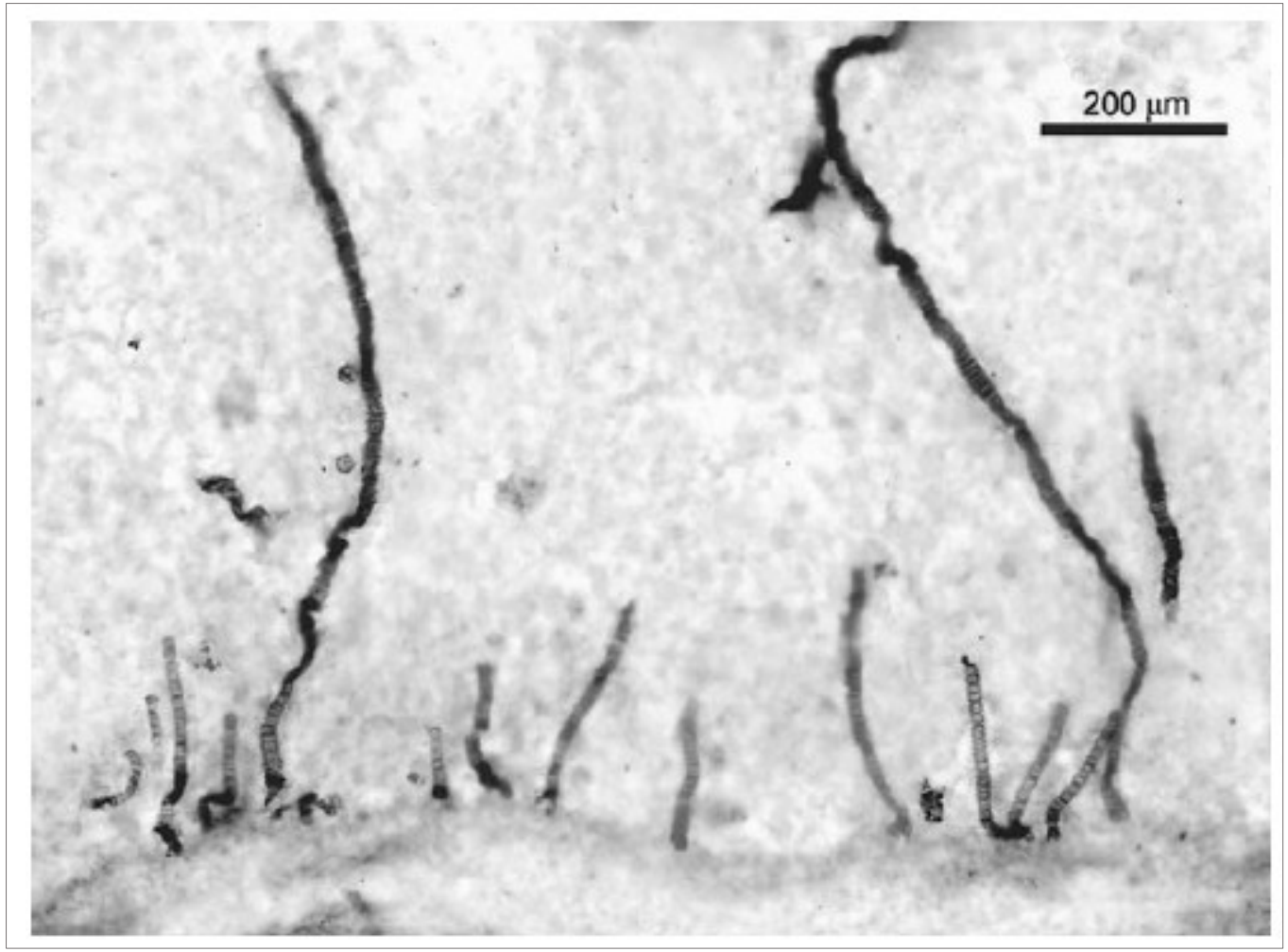
Microbial Mats



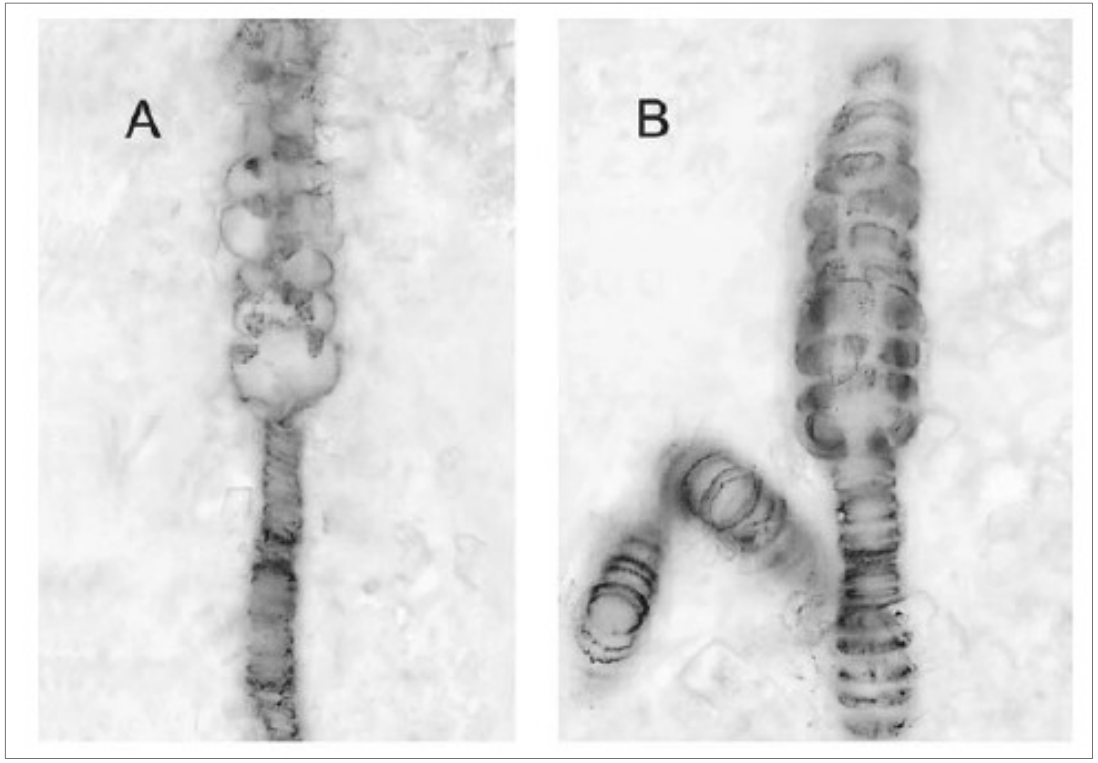




Fotos: T.R. Fairchild (IGc, US



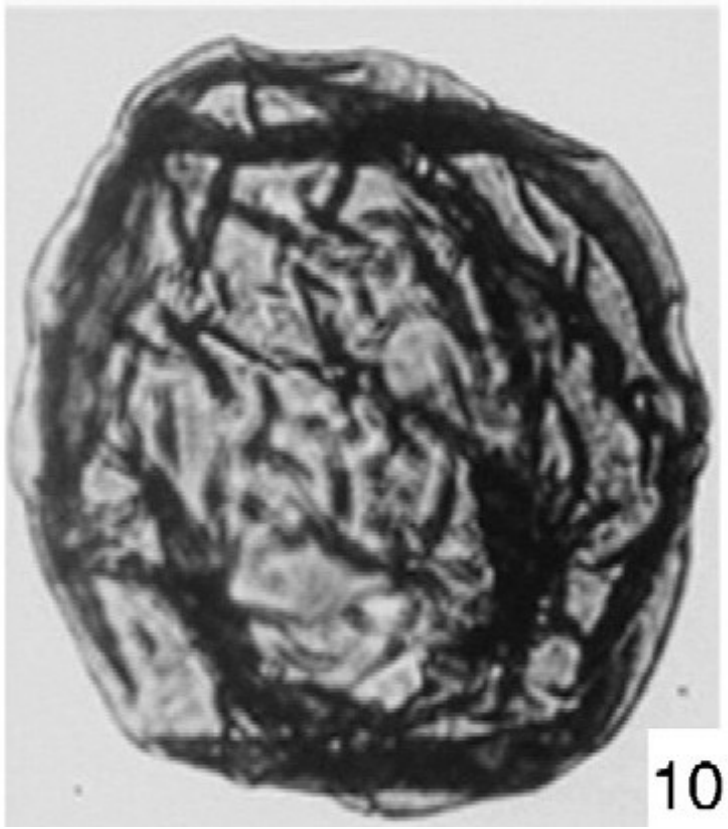
Bangiomorpha pubesces **Butterfield 2000**
Mesoproterozoic, Canada

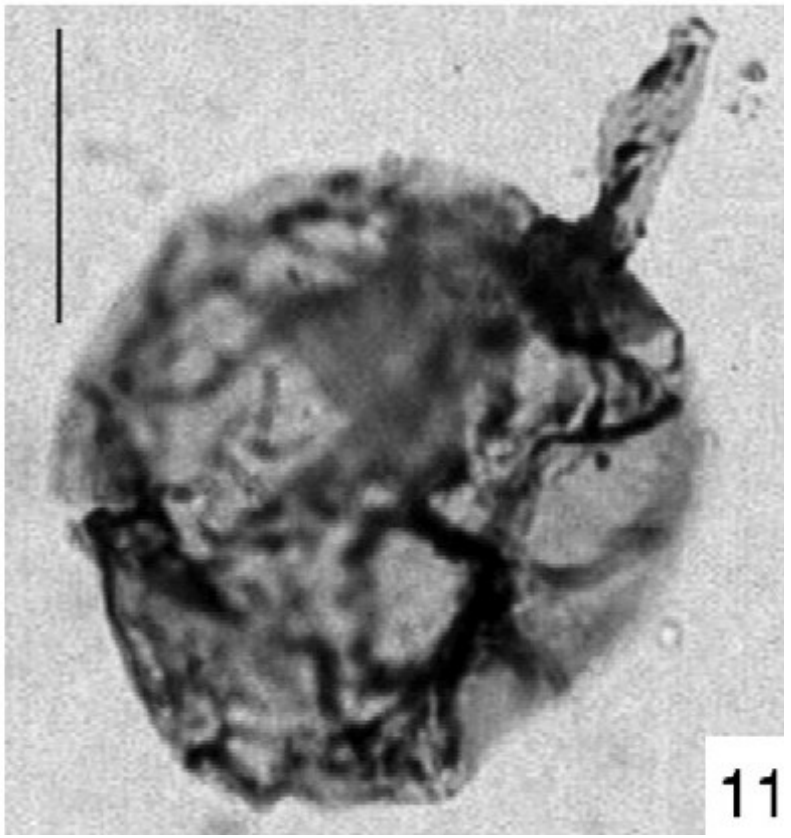


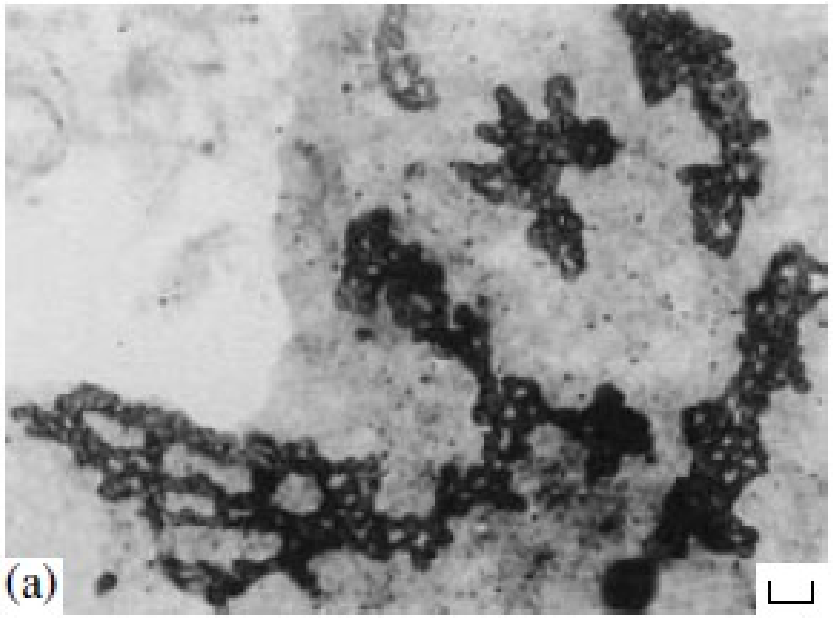
Sexual dimorphism

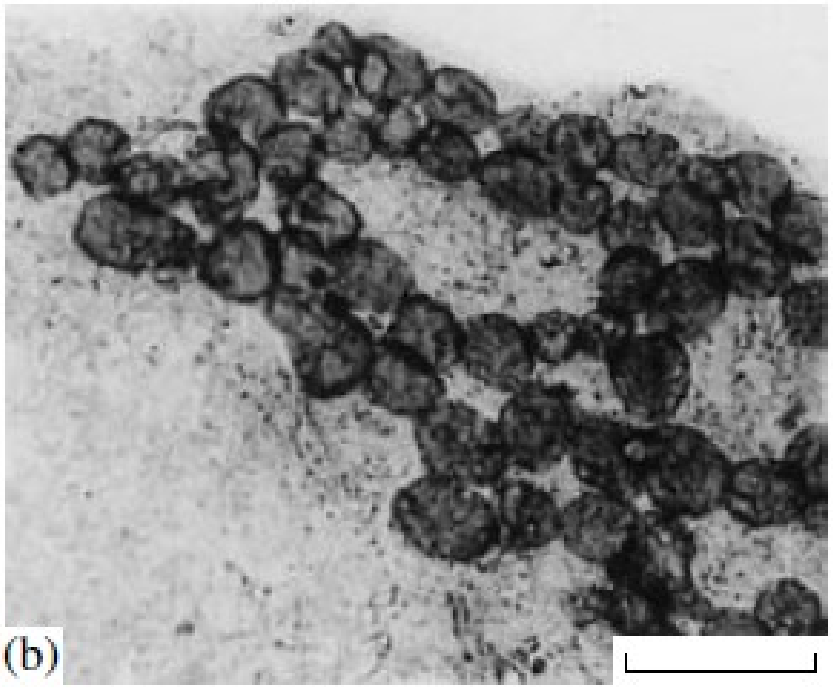
Acritarchs

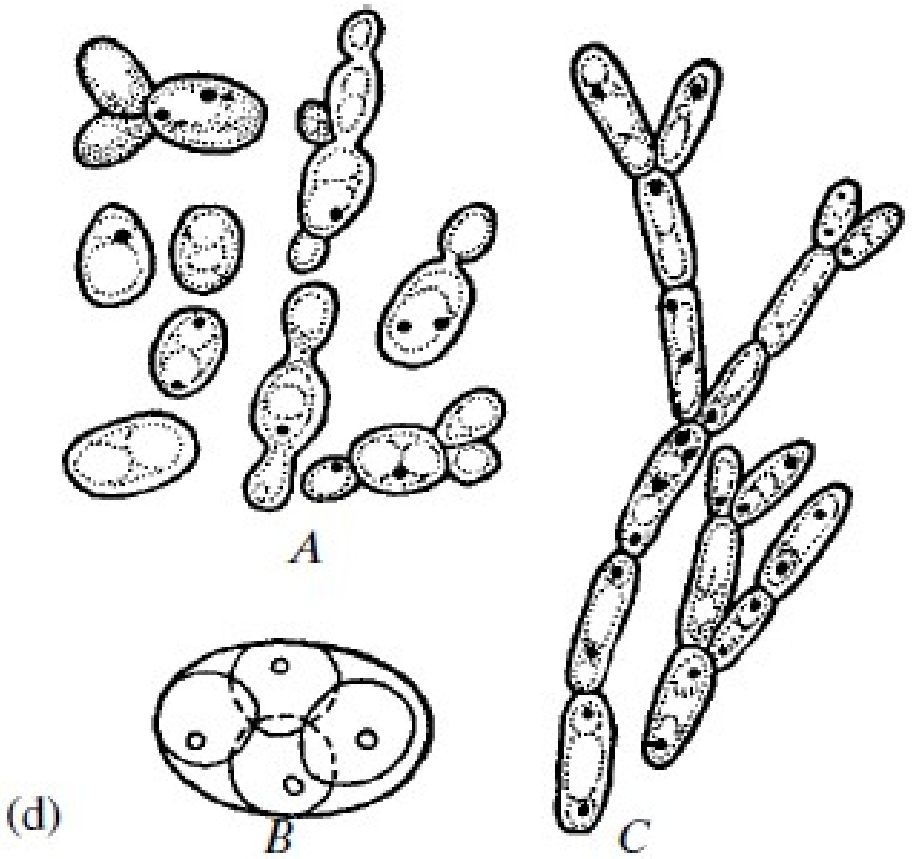
Oldest Eukaryotes

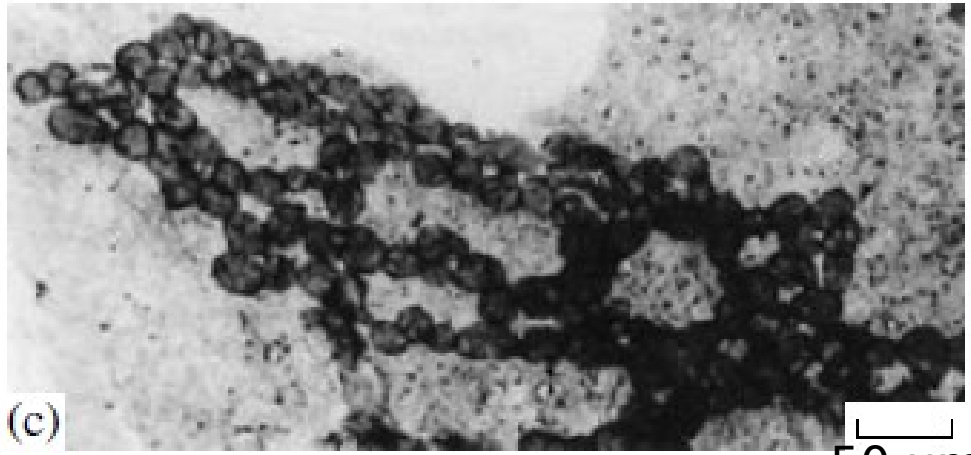












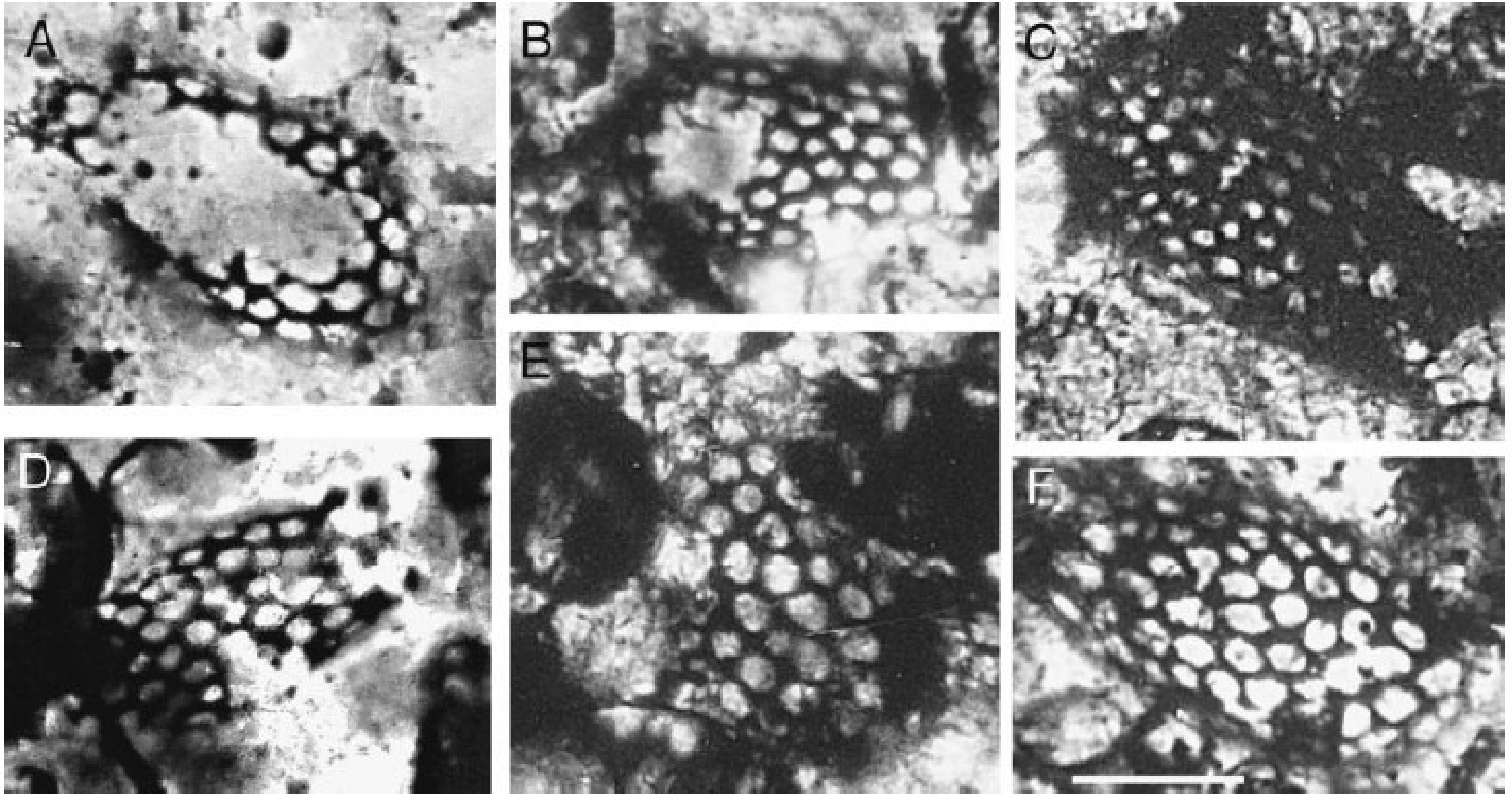
Hermann & Podkovyrov (2006)

Fungi

Oldest occurrence:
1.0 Ga,
Lakhanda Series,
Siberia

Molecular clocks:
1.5 Ga

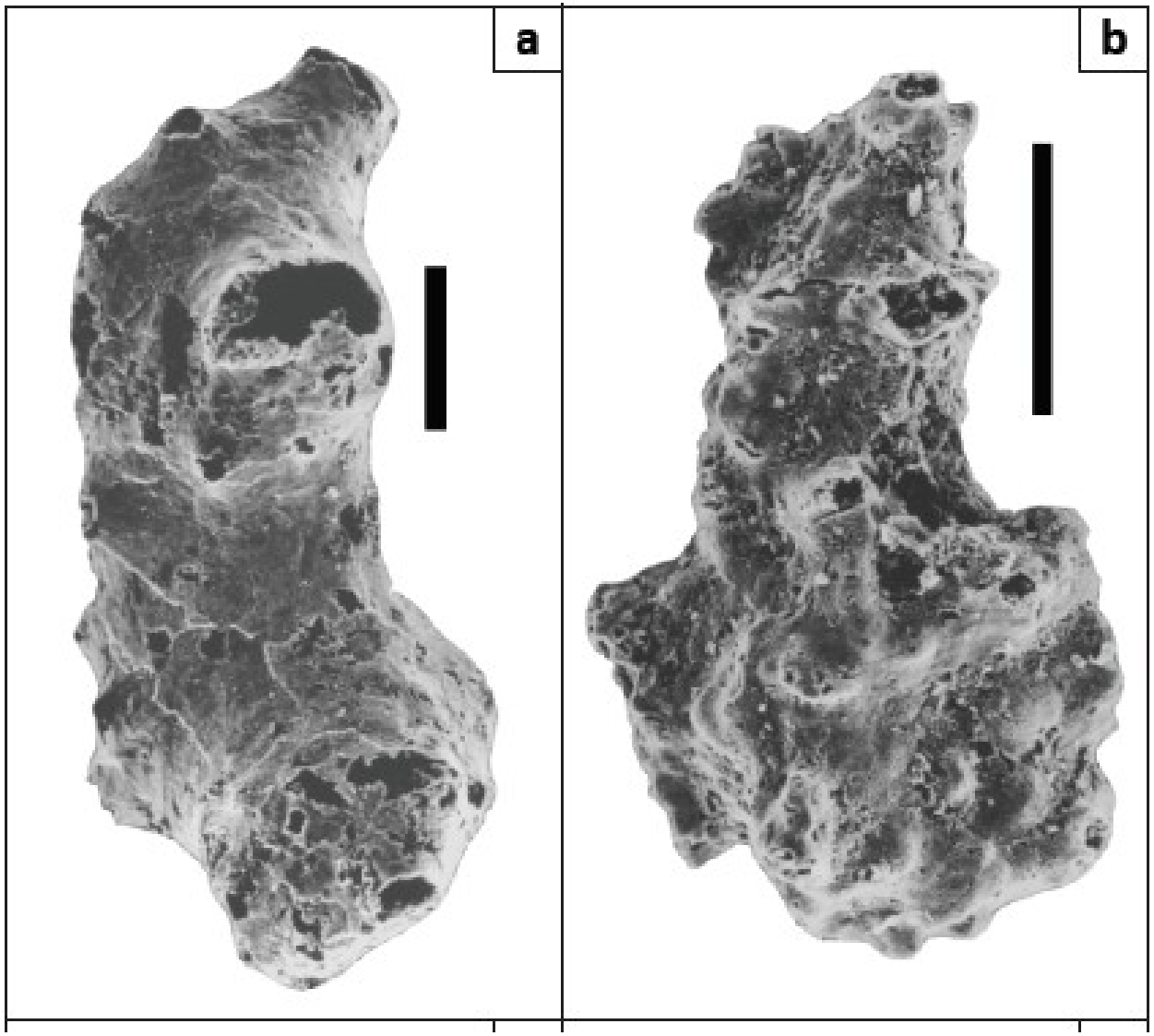
Vase-shaped microfossils

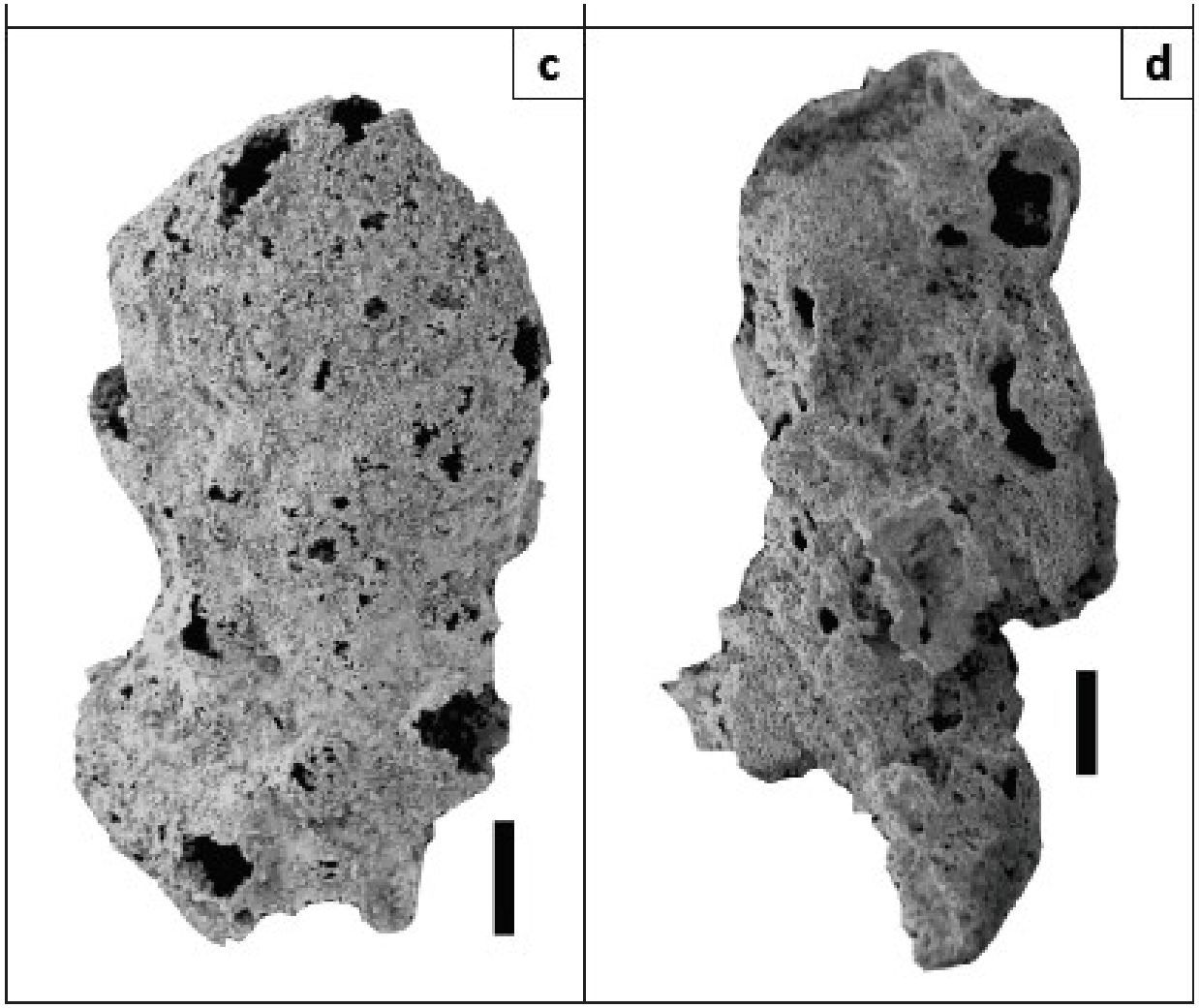


Porter & Knoll, 2000

Otavia antiqua

Porifera
Namibia, 760 Ma



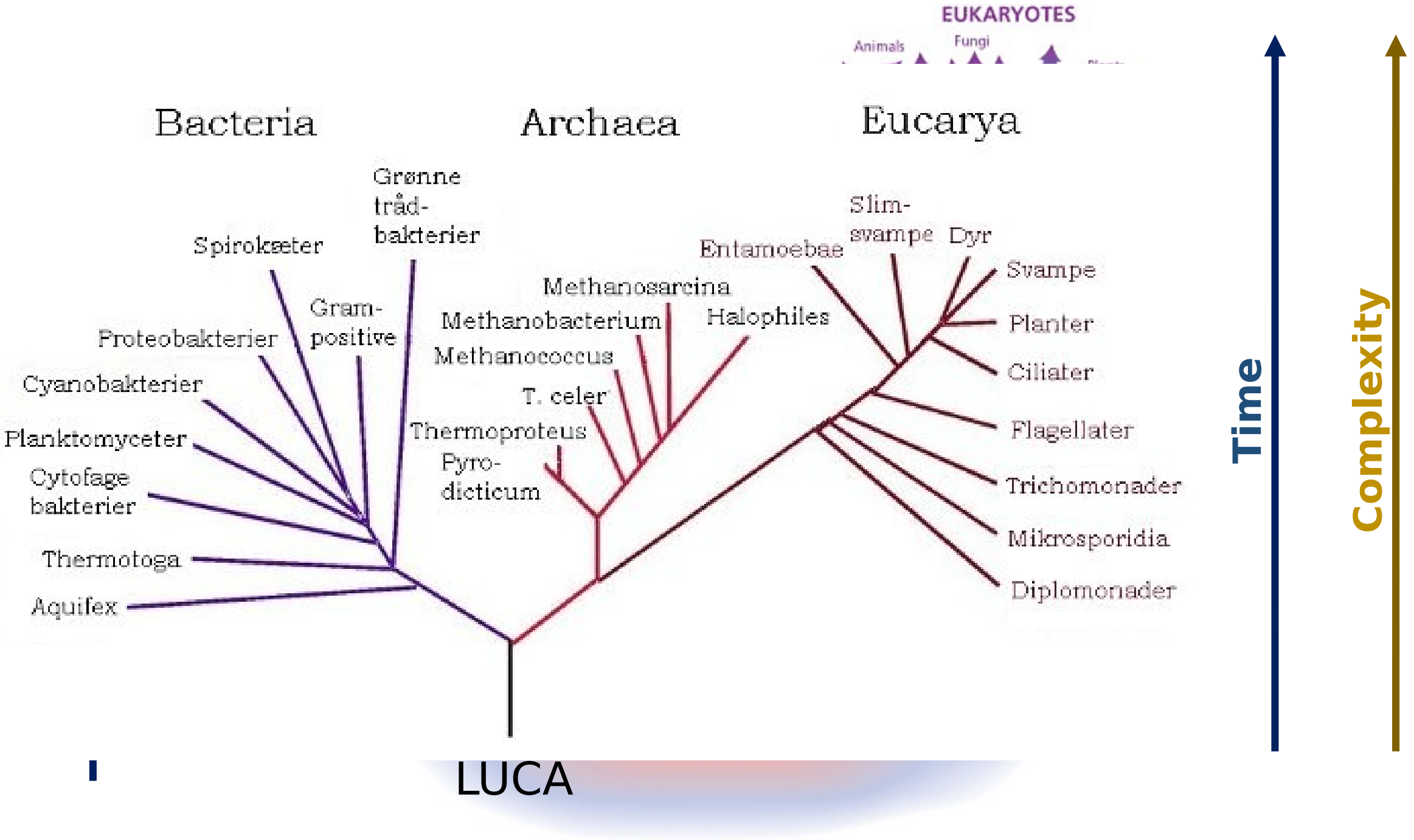


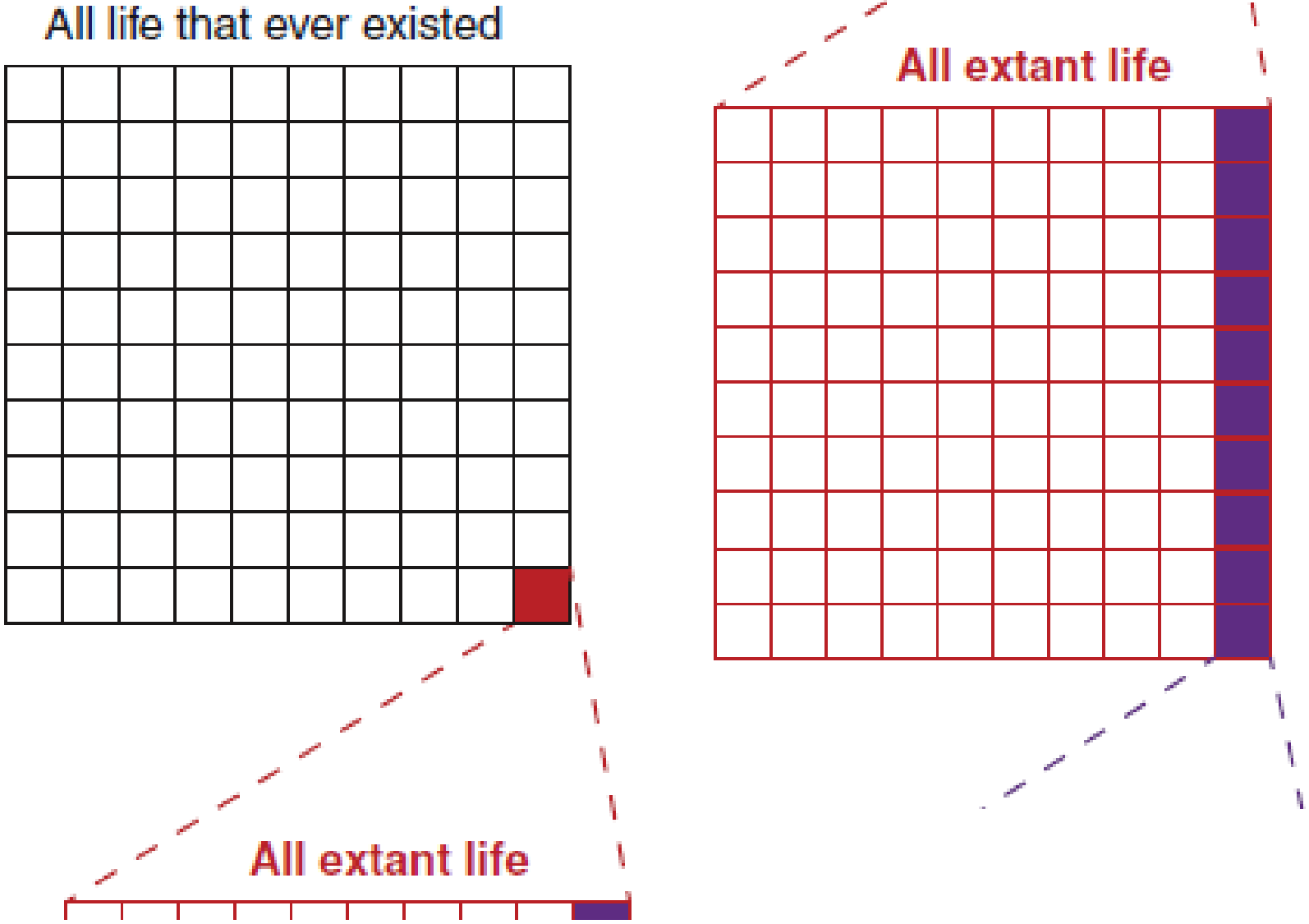
All scale bars are 100 µm.

Prave et al. (2007)

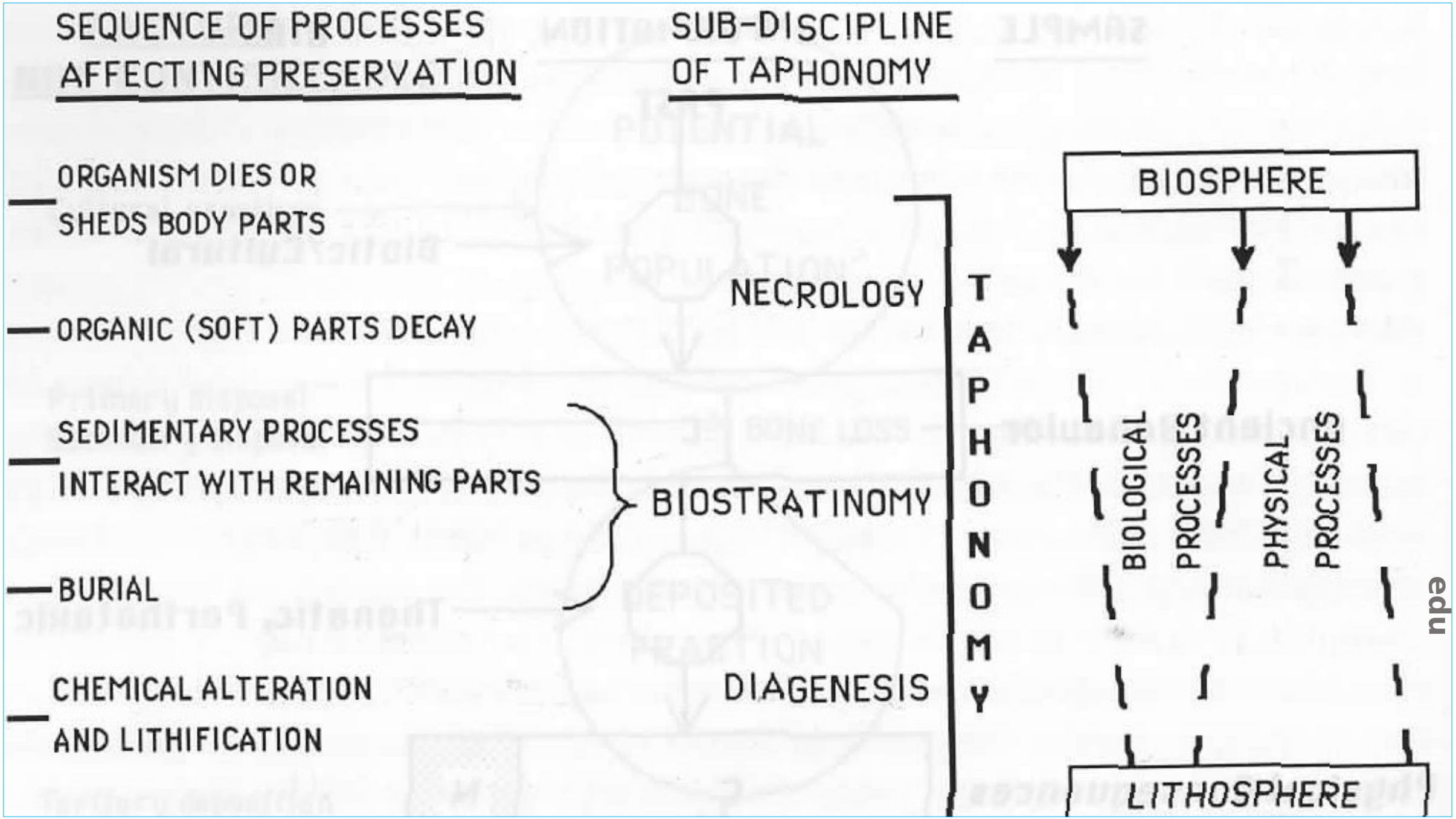
Precambrian Microfossils

Morphology

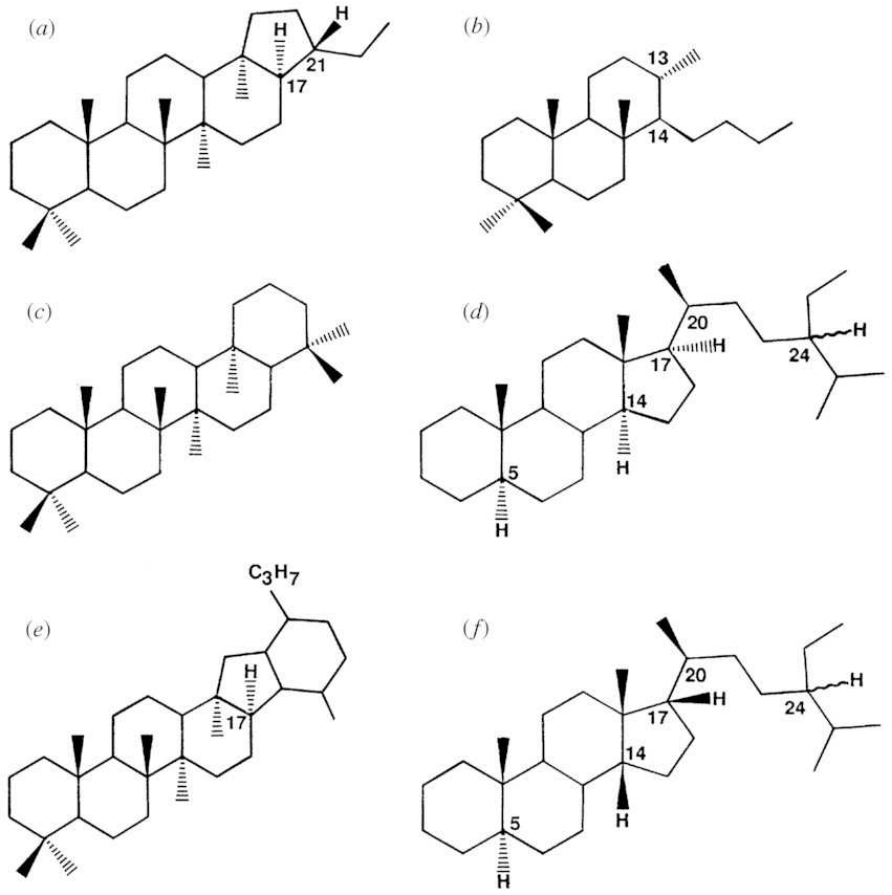

EUKARYOTES
Animals
Fungi
Bacteria
Archaea
Eucarya
Grønne tråd-bakterier
Spirokseter
Gram-positive
Proteobakterier
Cyanobakterier
Planktomyceter
Cytofage bakterier
Thermotoga
Aquifex
Methanosarcina
Methanobacterium
Methanococcus
T. celer
Thermoproteus
Pyro-dicticum
Halophiles
Entamoebae
Slim-svampe
Dyr
Svampe
Planter
Ciliater
Flagellater
Trichomonader
Mikrosporidia
Diplomonader
LUCA
Time
Complexity



Current Biology



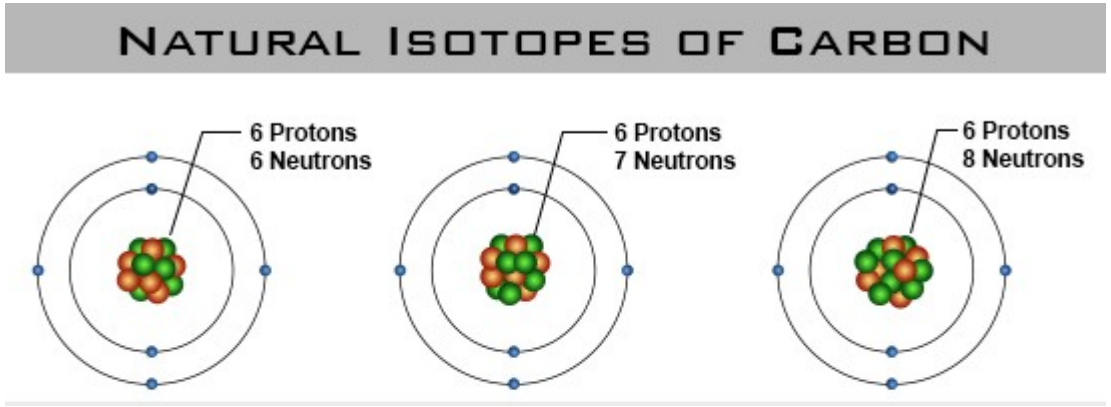
Biomarkers



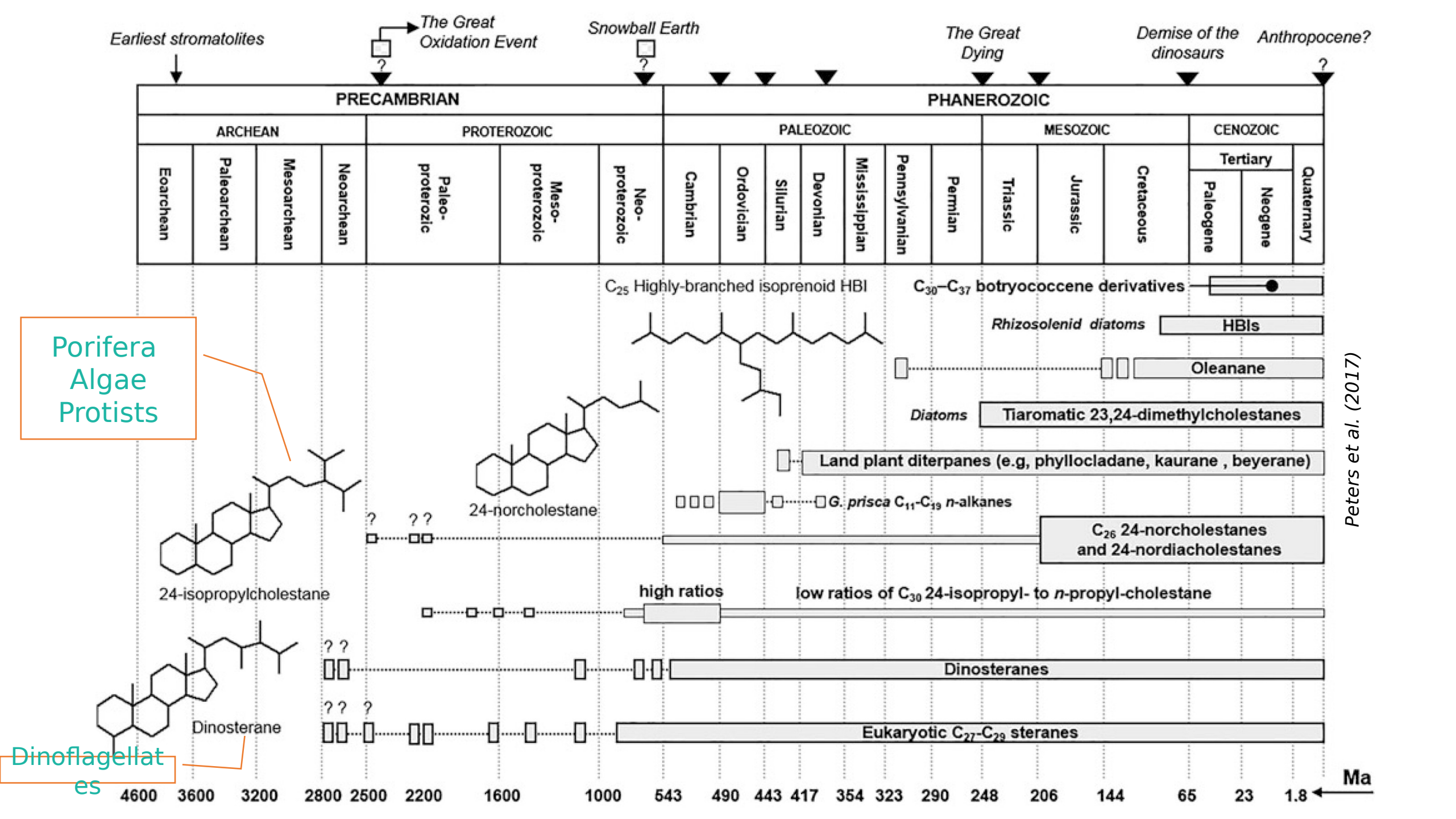
Connan (1999)

Organic matter and molecules
(C, O, H + acessory elements)

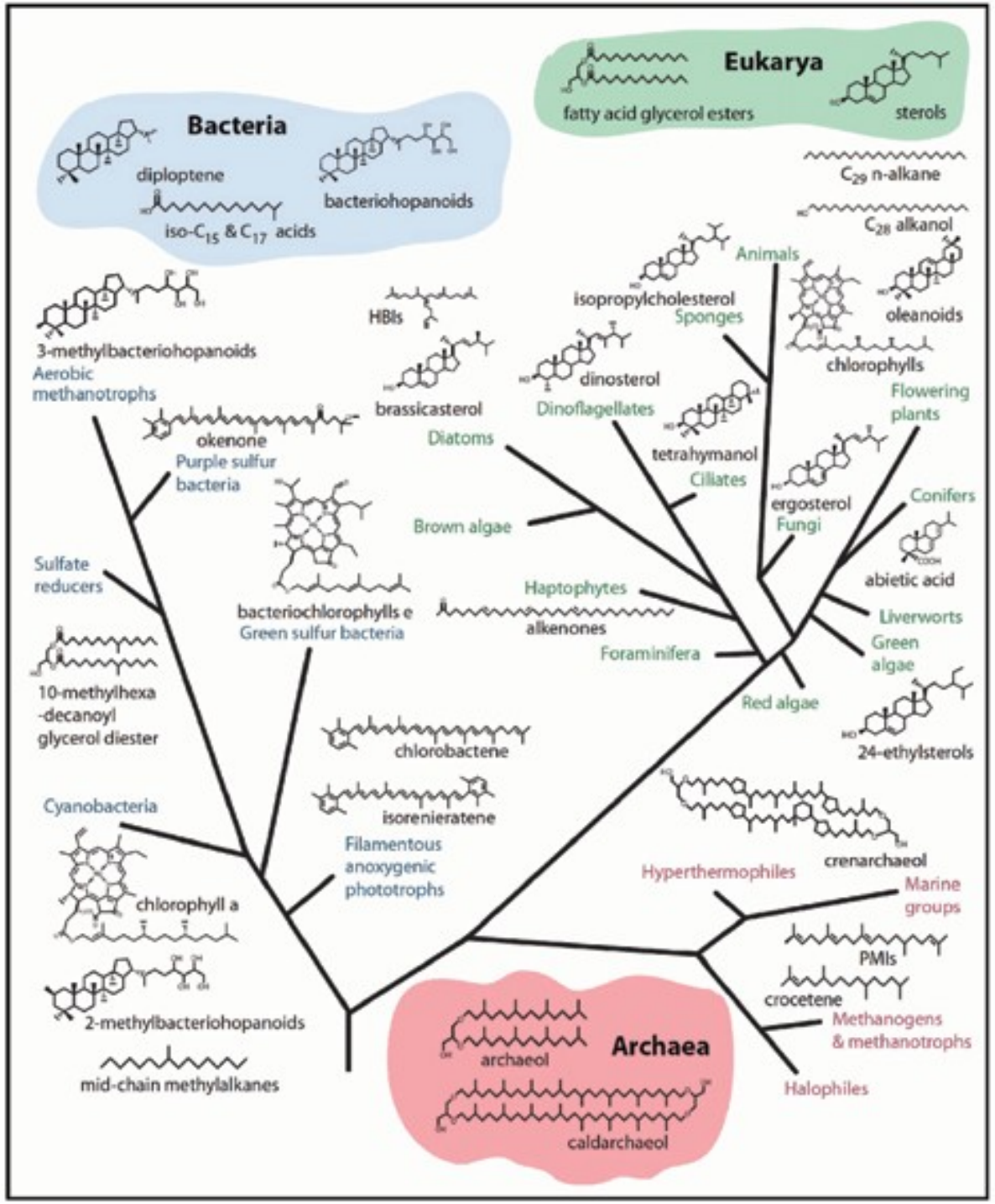
Isotopic ratio

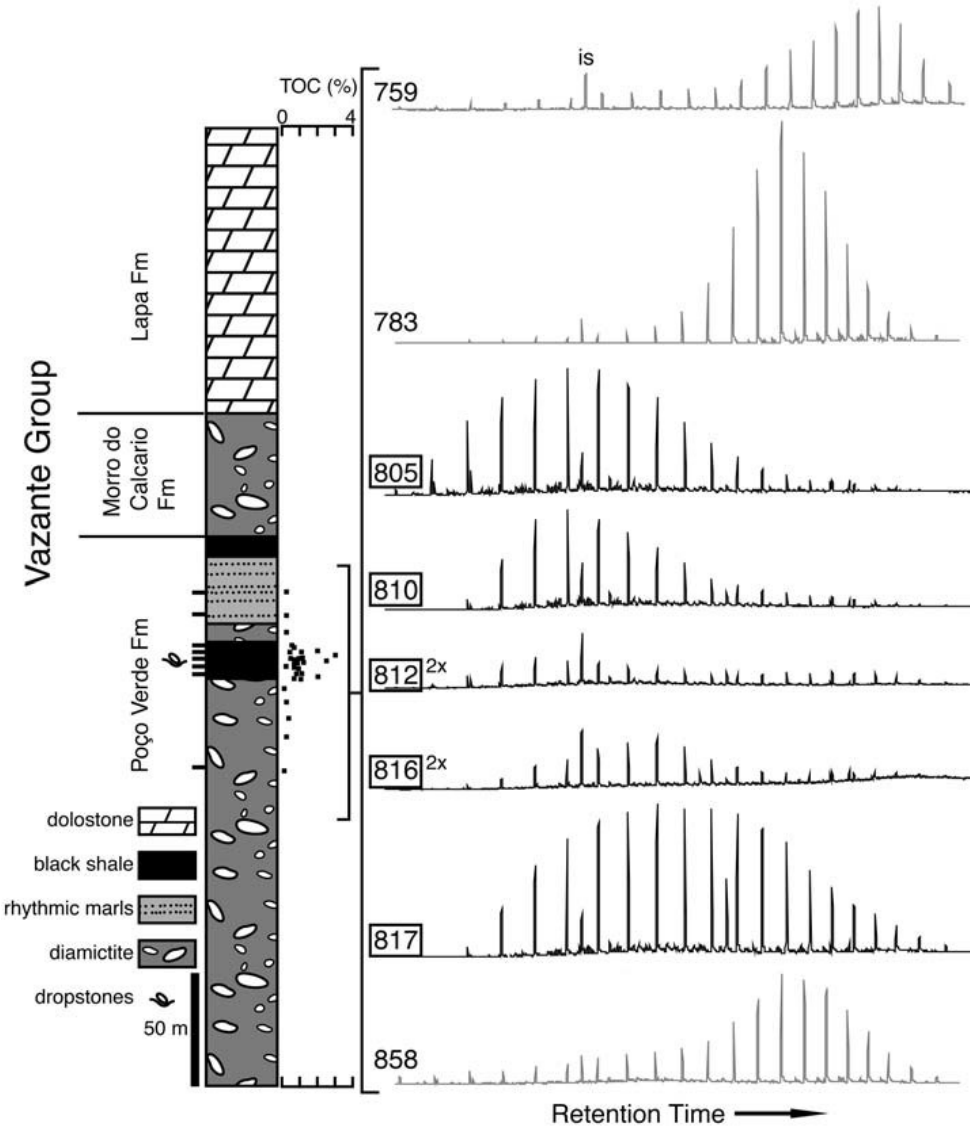


^{32}S	^{33}S	^{34}S	^{36}S
31.97207	32.97145	33.96786	35.96708
95.02%	0.75%	4.21%	0.02%
Stable	Stable	Stable	Stable


Earliest stromatolites
The Great Oxidation Event
Snowball Earth
The Great Dying
Demise of the dinosaurs
Anthropocene?
PRECAMBRIAN
PHANEROZOIC
ARCHEAN
PROTEROZOIC
PALEOZOIC
MESOZOIC
CENOZOIC
Eoarchean
Paleoarchean
Mesoarchean
Neoarchean
Paleo-proterozoic
Meso-proterozoic
Neo-proterozoic
Cambrian
Ordovician
Silurian
Devonian
Mississippian
Pennsylvanian
Permian
Triassic
Jurassic
Cretaceous
Tertiary
Paleogene
Neogene
Quaternary
Porifera
Algae
Protists
C25 Highly-branched isoprenoid HBI
C30–C37 botryococcene derivatives
Rhizosolenid diatoms
HBIs
Oleanane
Diatoms
Tiaromatic 23,24-dimethylcholestanes
Land plant diterpanes (e.g, phyllocladane, kaurane , beyerane)
24-norcholestane
G. prisca C11-C19 n-alkanes
C26 24-norcholestanes and 24-nordiacholestanes
24-isopropylcholestane
high ratios
low ratios of C30 24-isopropyl- to n-propyl-cholestane
Dinosteranes
Dinosterane
Eukaryotic C27-C29 steranes
Dinoflagellates
4600 3600 3200 2800 2500 2200 1600 1000 543 490 443 417 354 323 290 248 206 144 65 23 1.8
Ma
Peters et al. (2017)

Biomarker Evidence for Photosynthesis During Neoproterozoic Glaciation





Raja & Ramaswwamyreddy (2018)

Identifying abiotic sources of organic compounds

Synthesis and function of macromolecules in the origin of life

Early life and increasing complexity

Co-evolution of life and the physical environment

Identifying, exploring, and characterizing environments for habitability and biosignatures

Constructing habitable worlds

Challenges and opportunities in Astrobiology

Beyond natural sciences: humanities and social science contributions to Astrobiology

https://

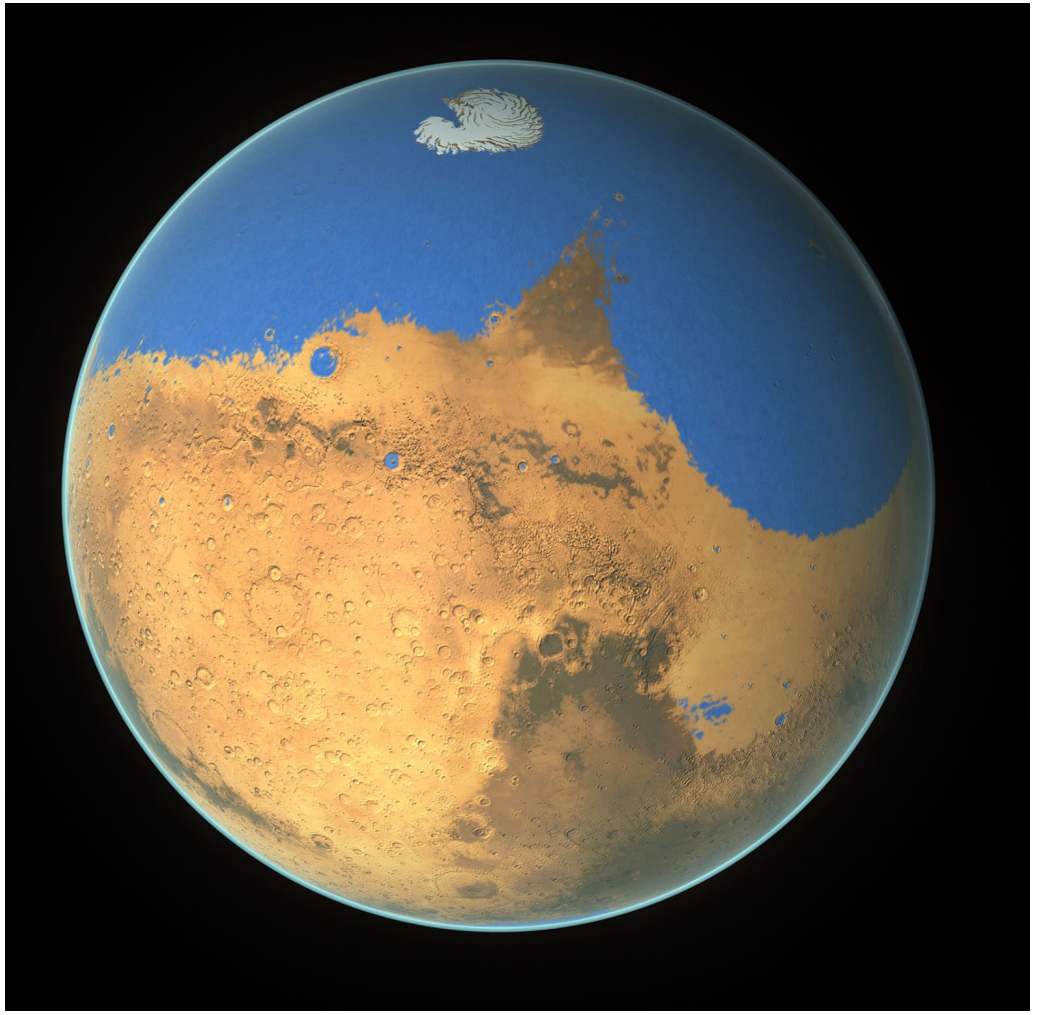
Questions

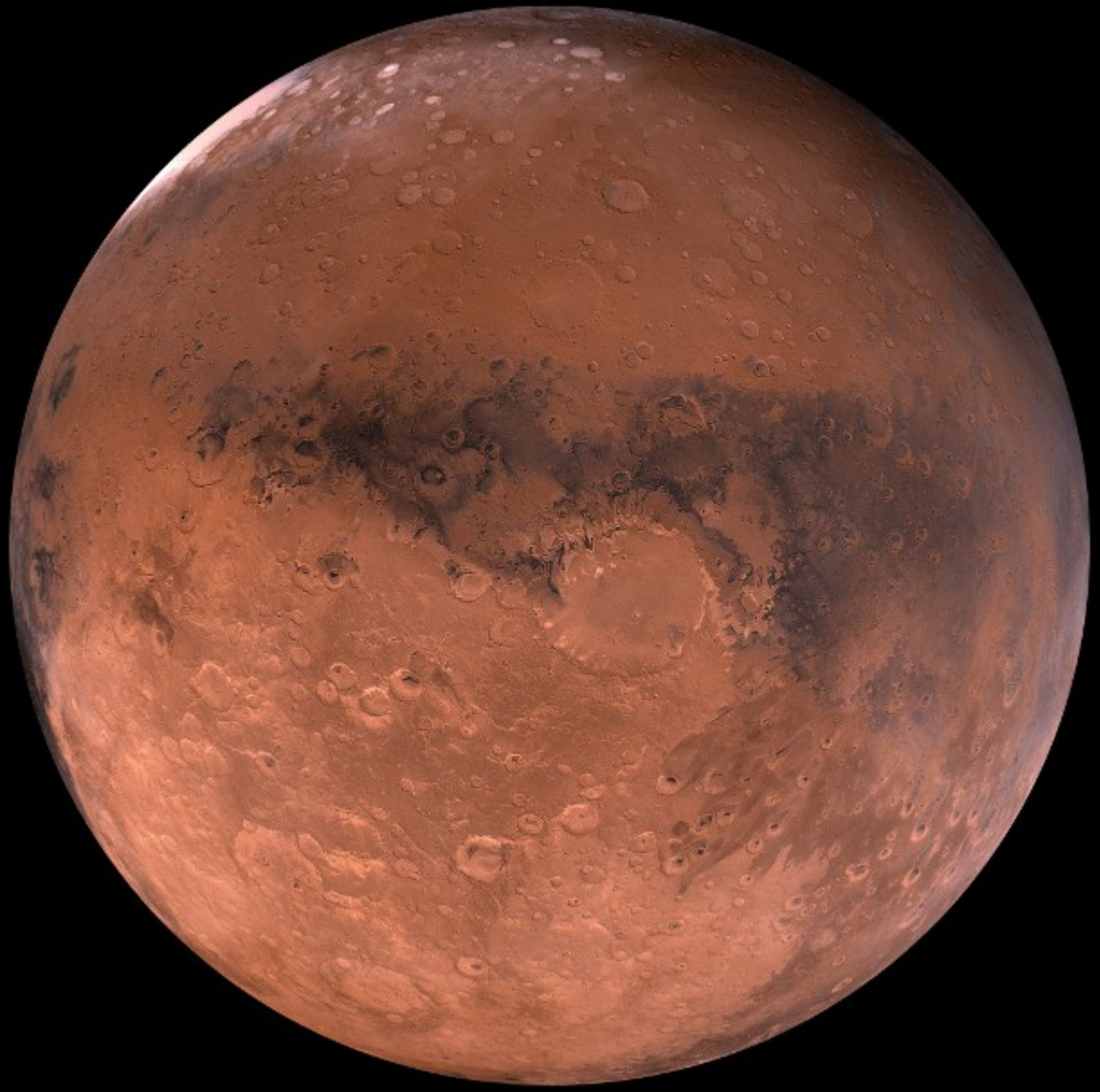
1. **When would life have become established on Mars?**

2. **Where would life have settled on Mars?**

3. **Where would life have expanded (colonized) to?**

4. **Where would life have persisted?**

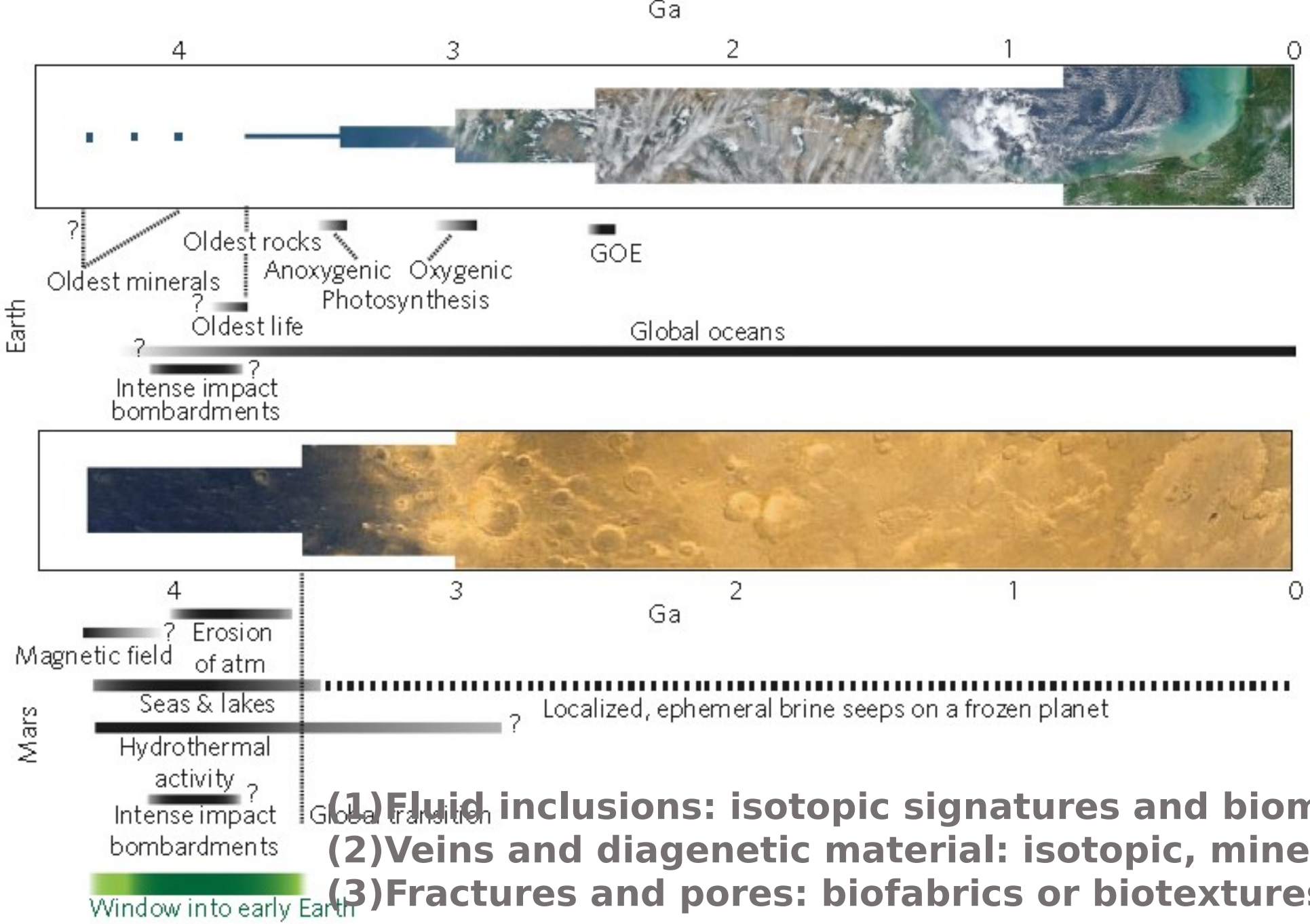




astrogeology.usgs.gov

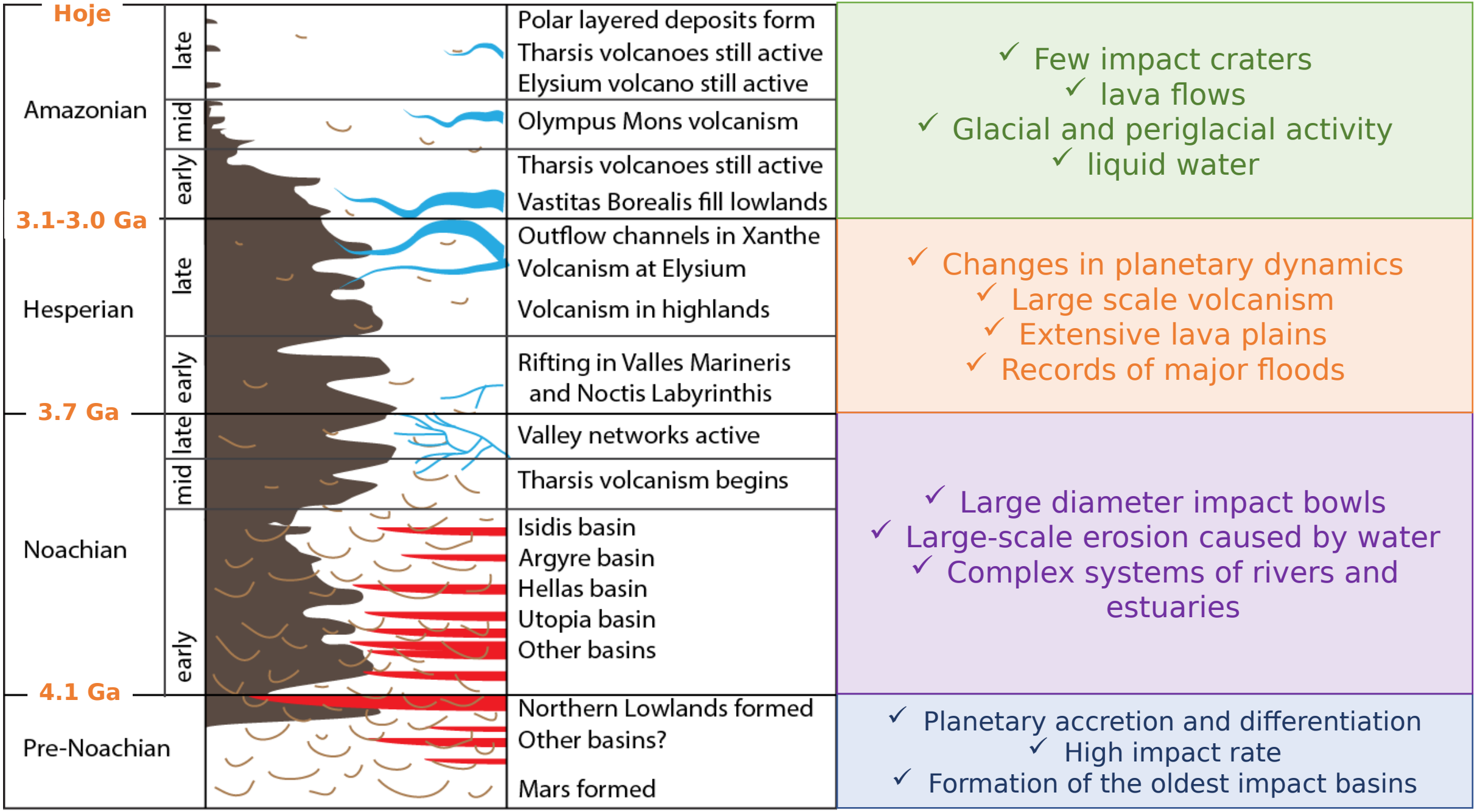
Five lines of research for the search for past life on other surfaces:

- ✓ Microfossils
- ✓ Biomarkers
- ✓ Biominerals or microorganisms/minerals interaction
- ✓ Bioweathering
- ✓ Sedimentary structures



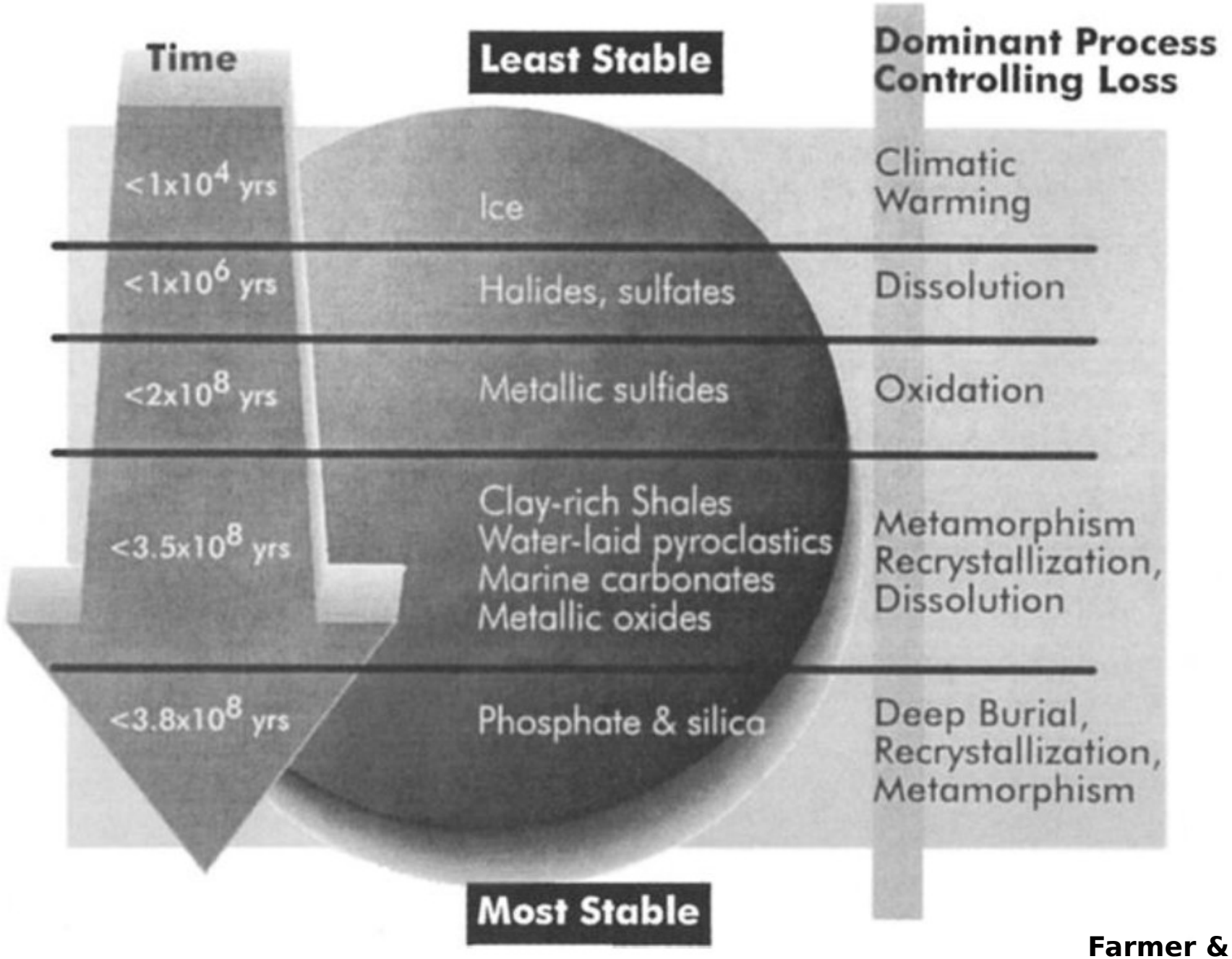
Michalski et al. (2008)

(1)Fluid inclusions: isotopic signatures and biomolecules
(2)Veins and diagenetic material: isotopic, mineral and microfossil si
(3)Fractures and pores: biofabrics or biotextures

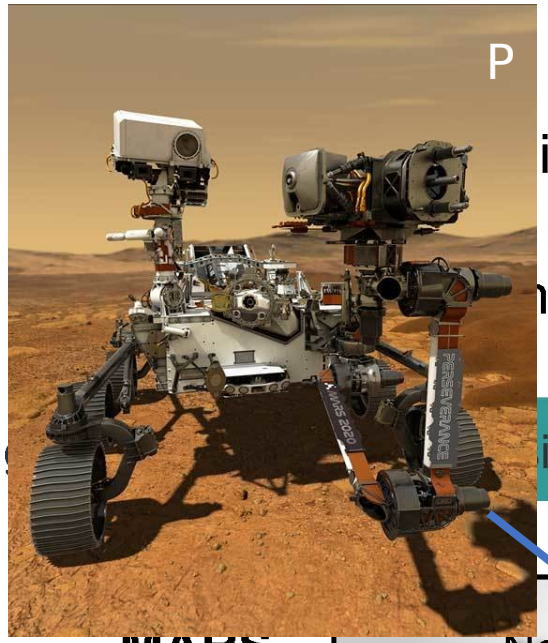


http://www.planetary.org

Paleoenvironments



Farmer & Des Marais (1999)



itable → le

neutral → a

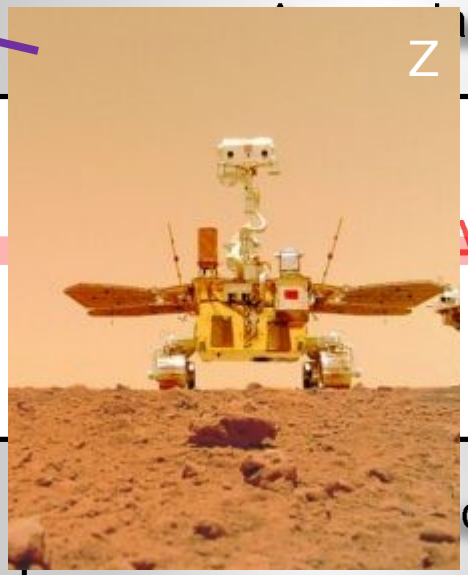
dry / frozen

ilicates | sulfa | anhydrous ferric oxides

MARS

Noachian | Hesperian | n

3.7 Ga



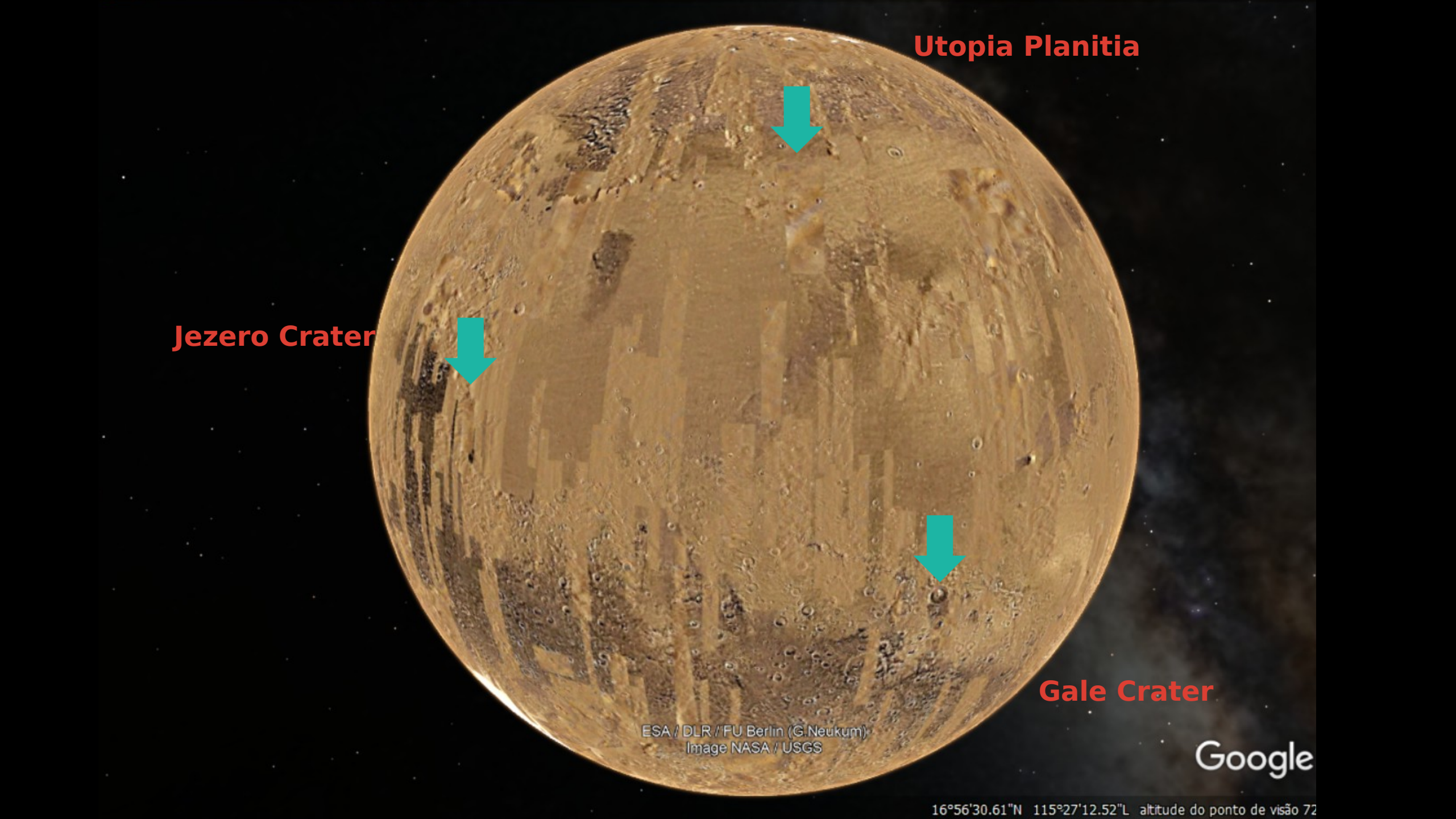
AL TIME

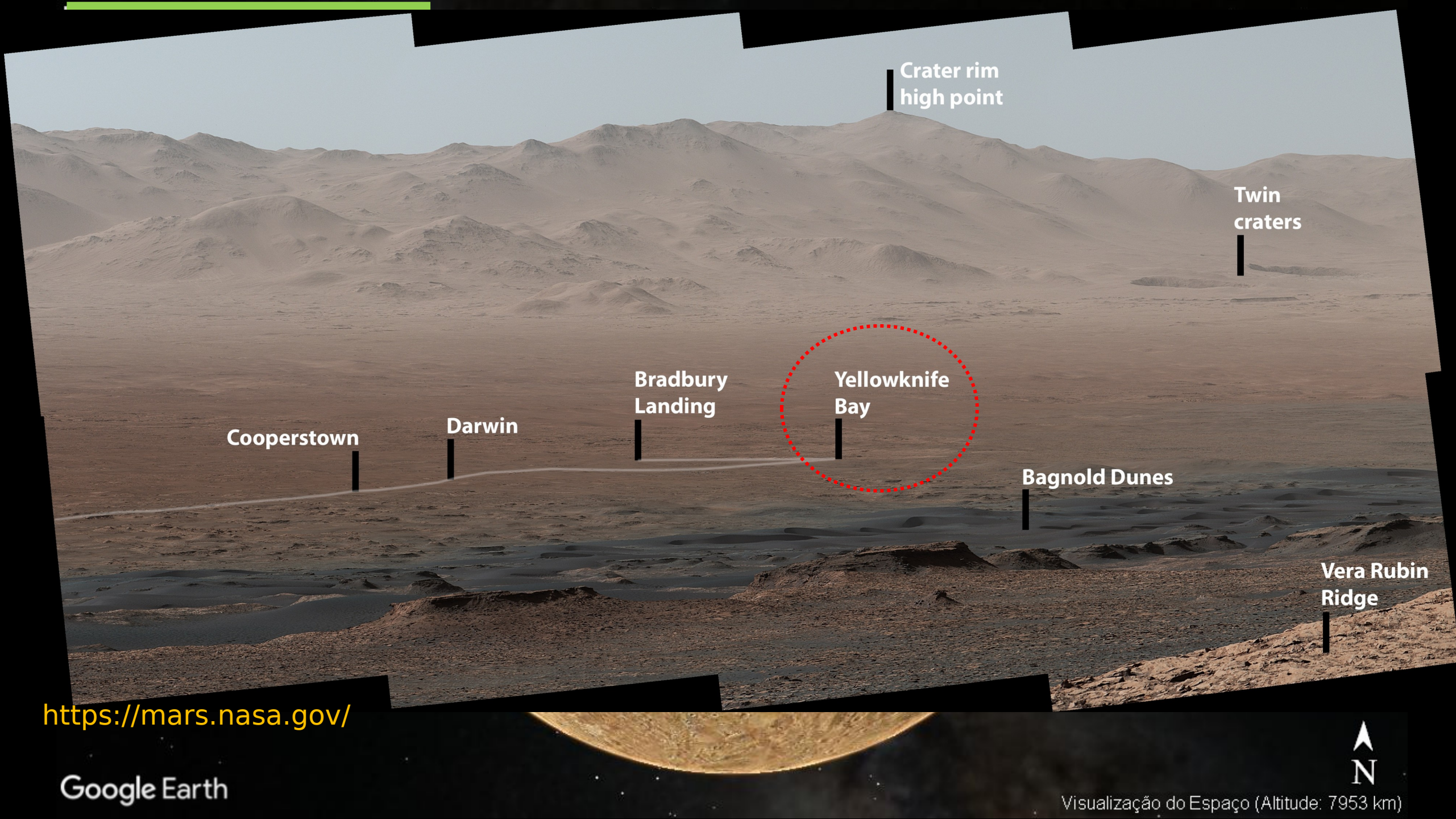
0 Ga

EARTH

Hadean | c | Phanerozoic

Adapted from Bibring et al. (2006)

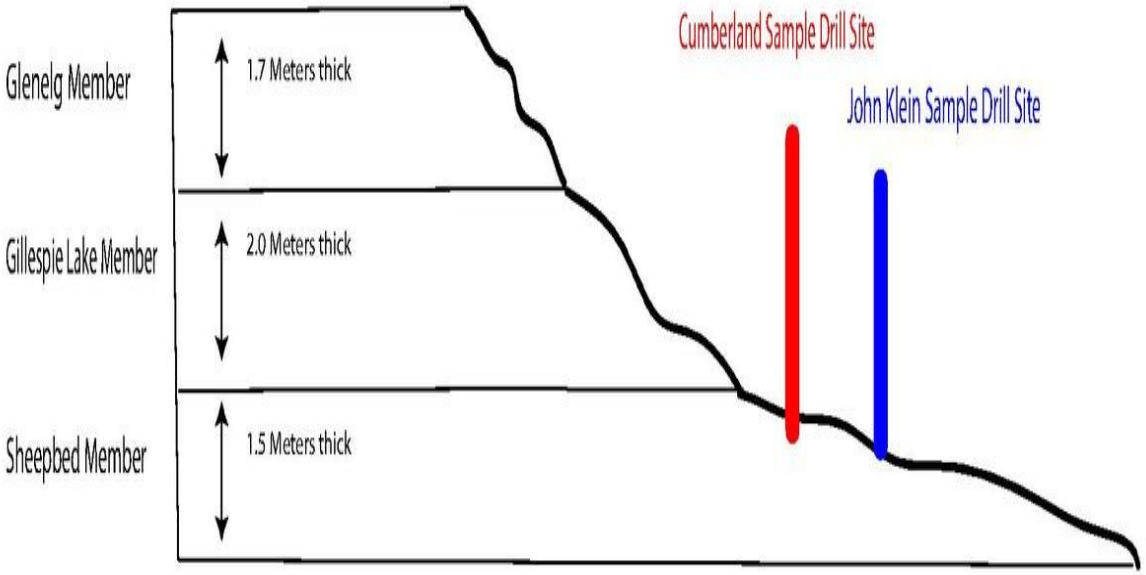

Utopia Planitia
Jezero Crater
Gale Crater
ESA / DLR / FU Berlin (G.Neukum)
Image NASA / USGS
Google
16°56'30.61"N 115°27'12.52"L altitude do ponto de visão 72

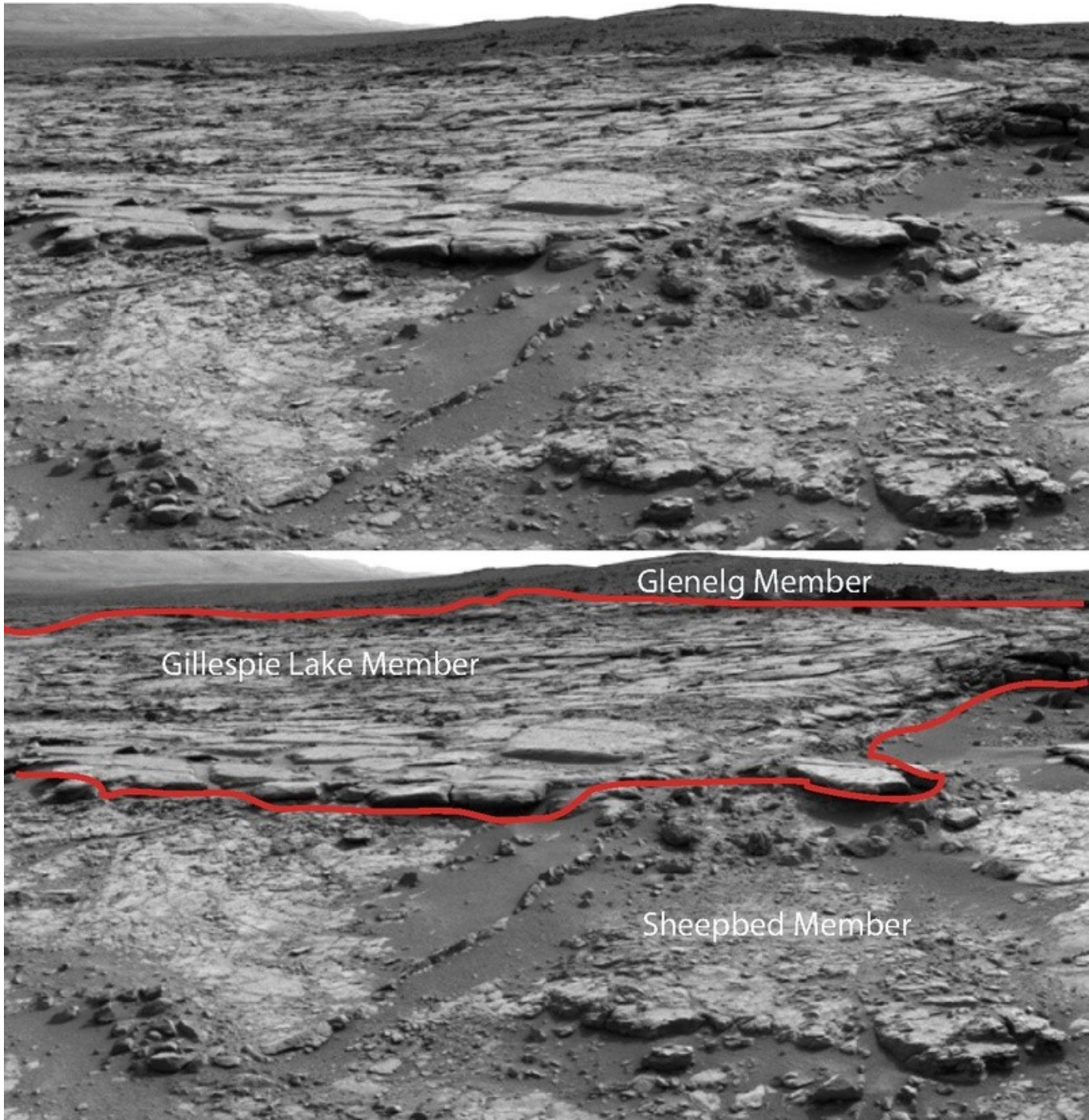

Crater rim high point
Twin craters
Bradbury Landing
Yellowknife Bay
Darwin
Cooperstown
Bagnold Dunes
Vera Rubin Ridge
https://mars.nasa.gov/
Google Earth
N
Visualização do Espaço (Altitude: 7953 km)

Yellowknife Bay sequence

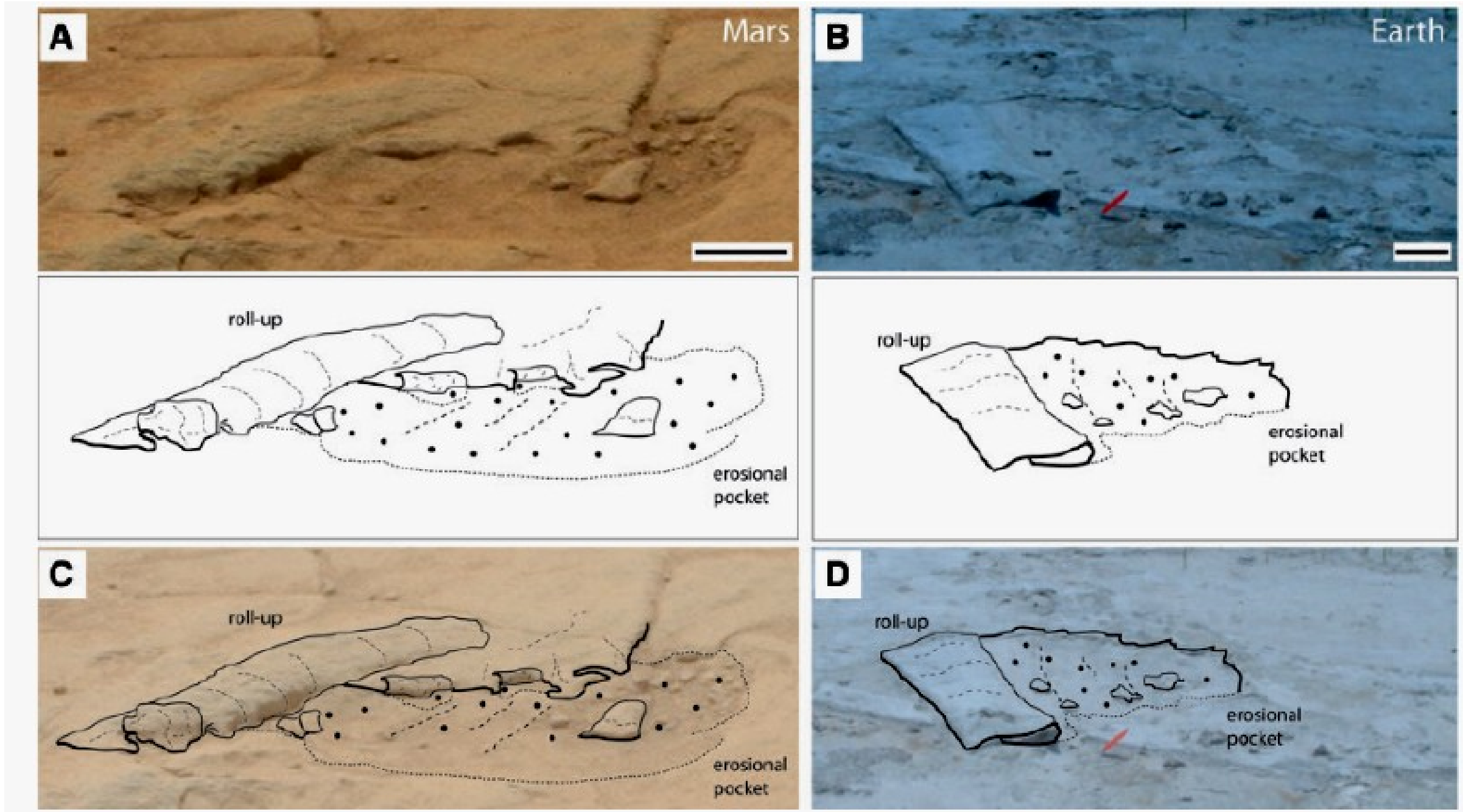
Lacustre (playa lake)

3.7 Ga

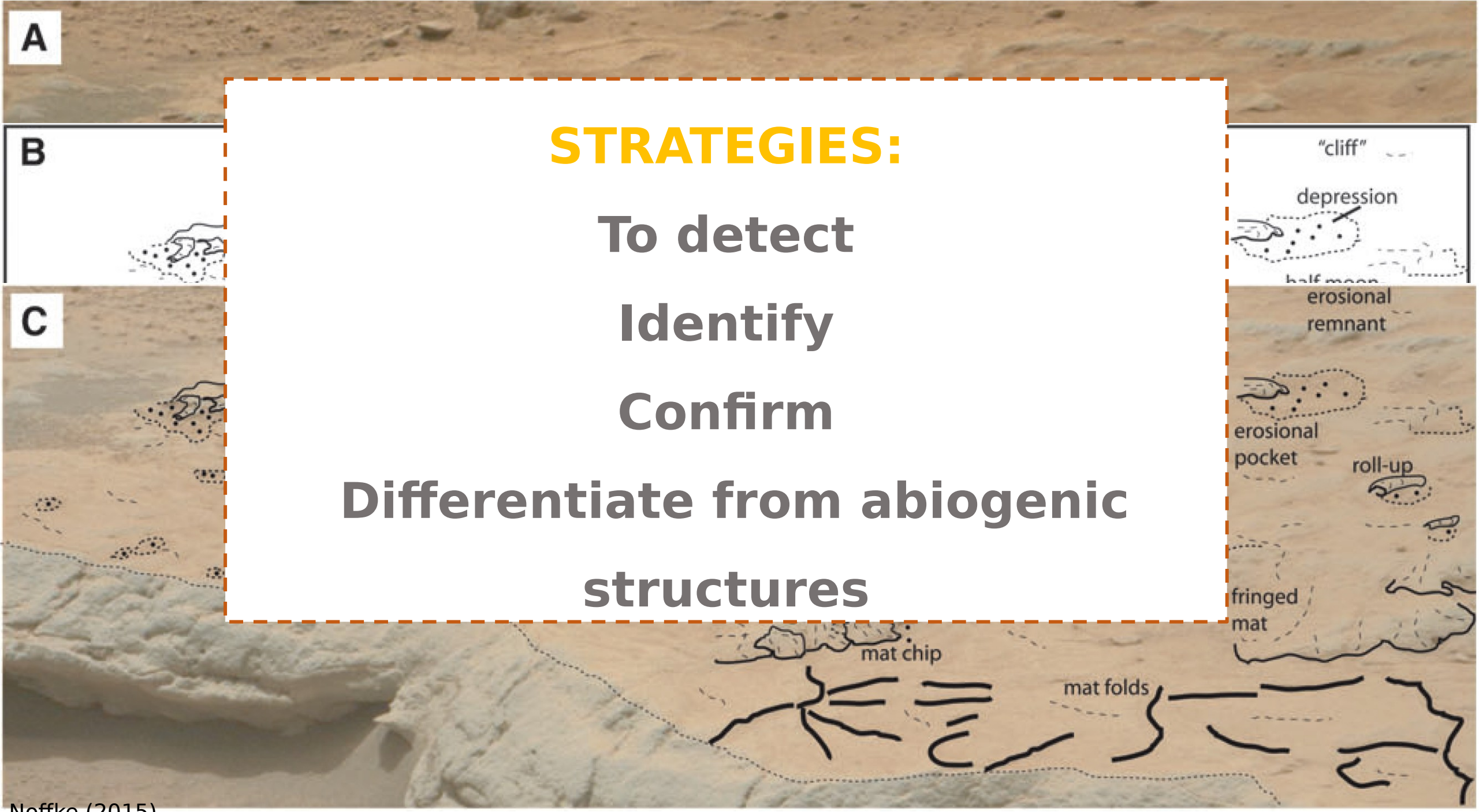




Imagens de www.wikiwand.com


A
Mars
B
Earth
roll-up
erosional pocket
roll-up
erosional pocket
C
roll-up
erosional pocket
D
roll-up
erosional pocket

Noffke (2015)



STRATEGIES:

To detect

Identify

Confirm

Differentiate from abiogenic structures

Noffke (2015)

Biomarkers

Parnell et al. (200

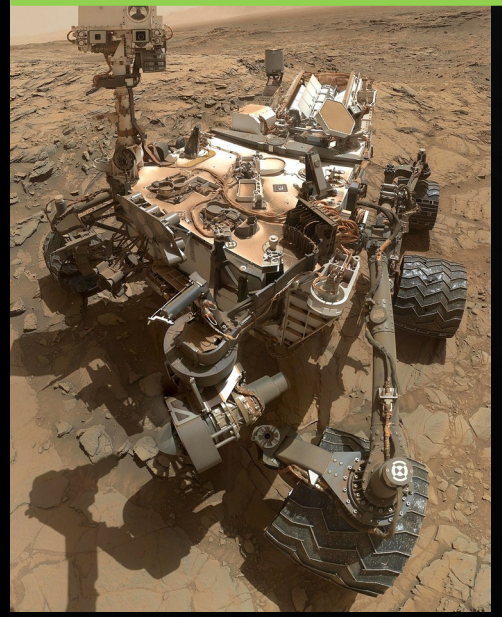
TABLE 2. SELECTION OF TARGET BIOMARKERS, THEIR LE

Target category no.	Priority	Biomarker	Mo
Extant			
1	A	ATP	Phos
2	A	Phosphoenolpyruvate	Phos
3	B	Acetyl phosphate	Phos
4	C	cyclic AMP	Phos
5	A	Generic pyrimidine base	Nucl
6	A	Generic purine base	Nucl
7	A	DNA	Nucl
8	A	Nicotinamide (generic NAD, NADP)	Vitar
9	C	Flavin (isoalloxazine ring)	Vitar
10	C	Fe-S centers	Redc
11	C	Quinones	Elect
12	B	Generic carotenoid	Pigm
13	C	Phycocyanin	Pigm
14	C	Thioesters	Ester
15	A	Generic extant porphyrin	Porp
16	B	Chaperones	Prote
17	A	ATP Synthase	Prote
18	A	Phytane	Hydr
19	A	Fatty acids (1 or 2)	Carb
20	A	Teichoic acid	Amino acid + phosphate polymer
21	A	LPS	Macromolecule
22	B	Ectoine	Compatible solute
23	C	Trehalose	Compatible solute
24	B	Squalene	Hydrocarbon
25	C	Diploptene	Hopanoid
26	B	Melanoidins	Macromolecule
		Sediment/cell extracts:	
27	C	1. Acid mine drainage	Multiple
28	C	2. Methanogens	Multiple
29	C	3. Cyanobacteria	Multiple
30	C	4. Mars energy users	Multiple
31	C	5. Extract/abiotic mix	Multiple
Fossil			
32	A	Generic isoprenoid	Hydrocarbon
33	A	Pristane	Hydrocarbon
18	A	Phytane	Hydrocarbon
34	A	β,β-carotane	Hydrocarbon
35	C	Tetramethyl benzenes	Hydrocarbon
36	C	Tetramethyl cyclohexanes	Hydrocarbon
37	C	Squalane	Hydrocarbon
38	A	Generic ABC terpane	Hydrocarbon
39	A	Generic hopane	Hydrocarbon
40	C	Gammacerane	Hydrocarbon
41	B	Generic diasterane	Hydrocarbon

Target category no.	Priority	Biomarker	Mo	Yes/No	
20	A	Teichoic acid	Amino acid + phosphate polymer	Yes	Gram-positive wall
21	A	LPS	Macromolecule	Yes	Gram-negative wall
22	B	Ectoine	Compatible solute	Yes	Osmotic protectant
23	C	Trehalose	Compatible solute	Yes	Osmotic protectant
24	B	Squalene	Hydrocarbon	No	Lipid biosynthesis (isoprenoid precursor)
25	C	Diploptene	Hopanoid	No	Bacterial membrane
26	B	Melanoidins	Macromolecule	No	Sugar degradation
		Sediment/cell extracts:			
27	C	1. Acid mine drainage	Multiple	Some	Whole cells
28	C	2. Methanogens	Multiple	Some	Whole cells
29	C	3. Cyanobacteria	Multiple	Some	Whole cells
30	C	4. Mars energy users	Multiple	Some	Whole cells
31	C	5. Extract/abiotic mix	Multiple	Some	Whole cells
Fossil					
32	A	Generic isoprenoid	Hydrocarbon	No	Chlorophyll, quinones, archeal membranes
33	A	Pristane	Hydrocarbon	No	Chlorophyll, quinones, archeal membranes
18	A	Phytane	Hydrocarbon	No	Chlorophyll, quinones, archeal membranes
34	A	β,β-carotane	Hydrocarbon	No	Fossil carotenoids
35	C	Tetramethyl benzenes	Hydrocarbon	No	Fossil carotenoids
36	C	Tetramethyl cyclohexanes	Hydrocarbon	No	Fossil carotenoids
37	C	Squalane	Hydrocarbon	No	Membranes (prokaryotes)
38	A	Generic ABC terpane	Hydrocarbon	No	Membranes (prokaryotes)
39	A	Generic hopane	Hydrocarbon	No	Membranes (prokaryotes)
40	C	Gammacerane	Hydrocarbon	No	Membranes (prokaryotes)
41	B	Generic diasterane	Hydrocarbon	No	Membranes (eukaryotes and prokaryotes)

Gale Crater

Exploration area of Curiosity



Thiophene (C_4H_4S)

Aromatic compounds

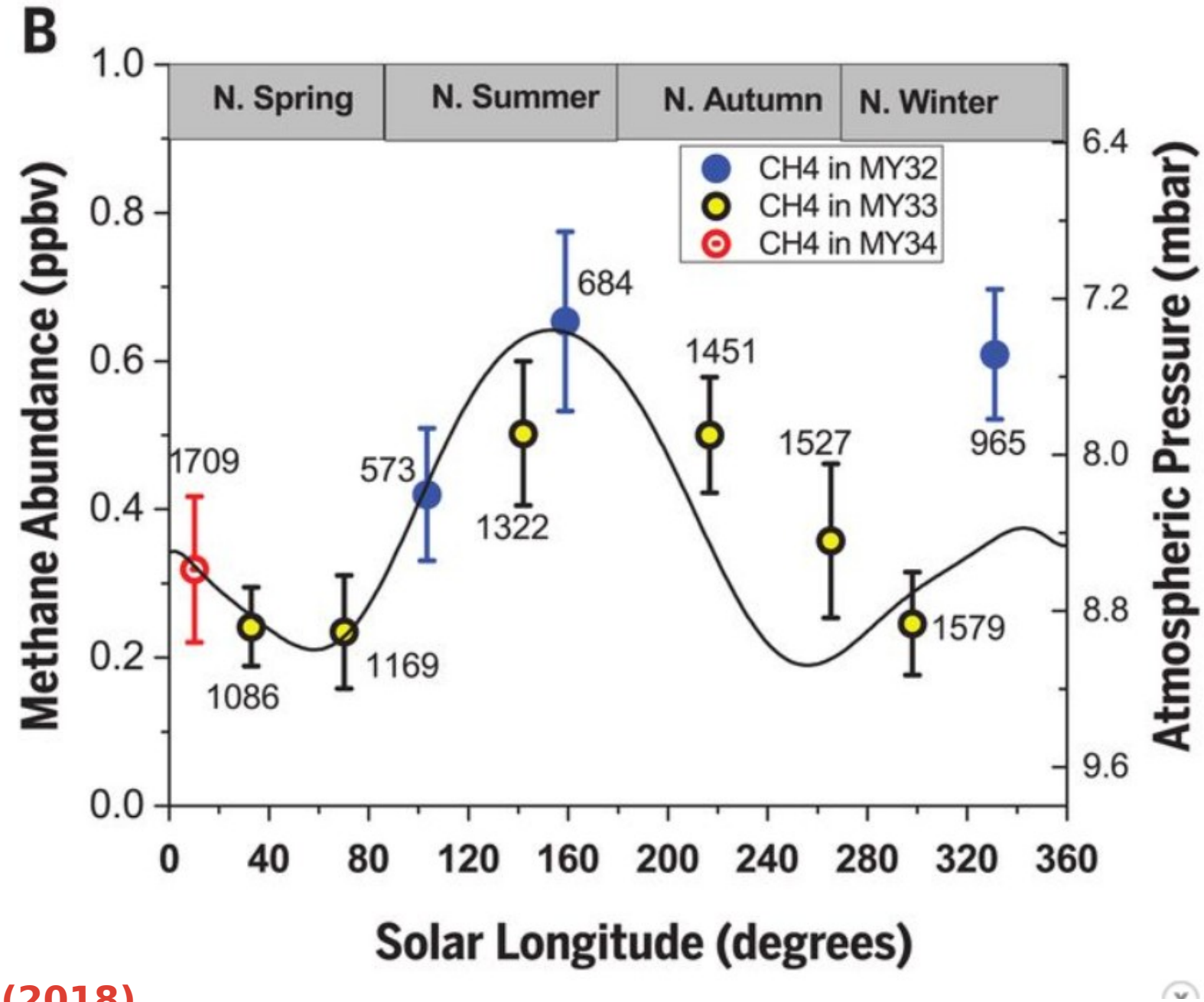
Eigenbrode et al. (2018)

Aliphatic compounds

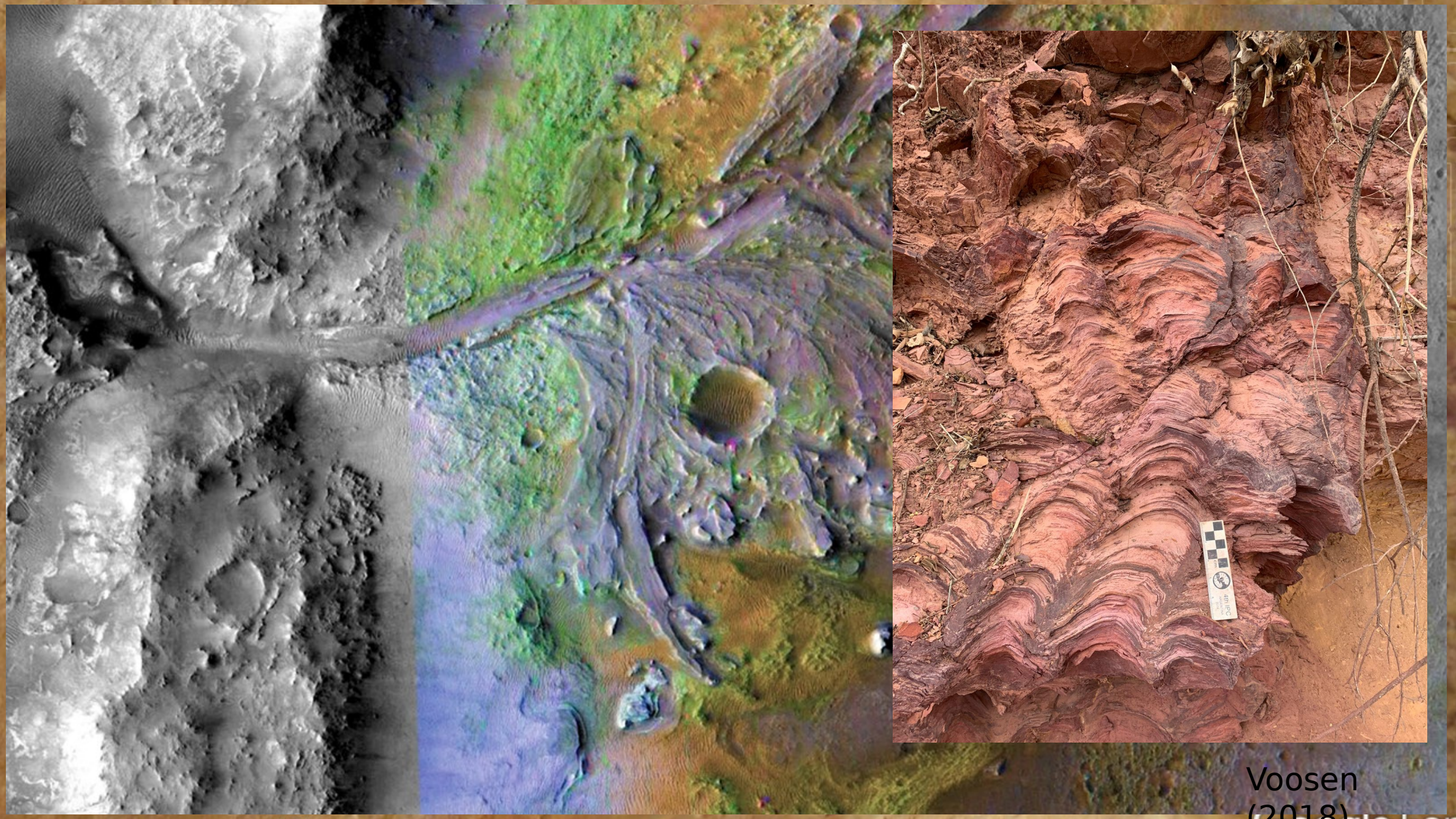
Google Earth

N

Visualização do Espaço (Altitude: 7953 km)



Webster et al. (2018)


17.8 km
Voosen (2018)
Google Earth

Types of fossils

Fossils

Applications

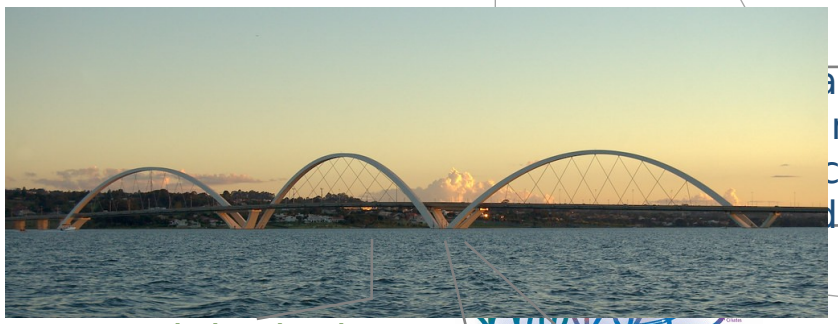
Relative age dating

Biological Evolution

Record of past life = 10 Ky

Earth System Evolution

Paleontology



Biological affinity

Paleoecological

Preservation

Other planets and moons

Earth

Past, presente and future

Life in a cosmical context

Comets

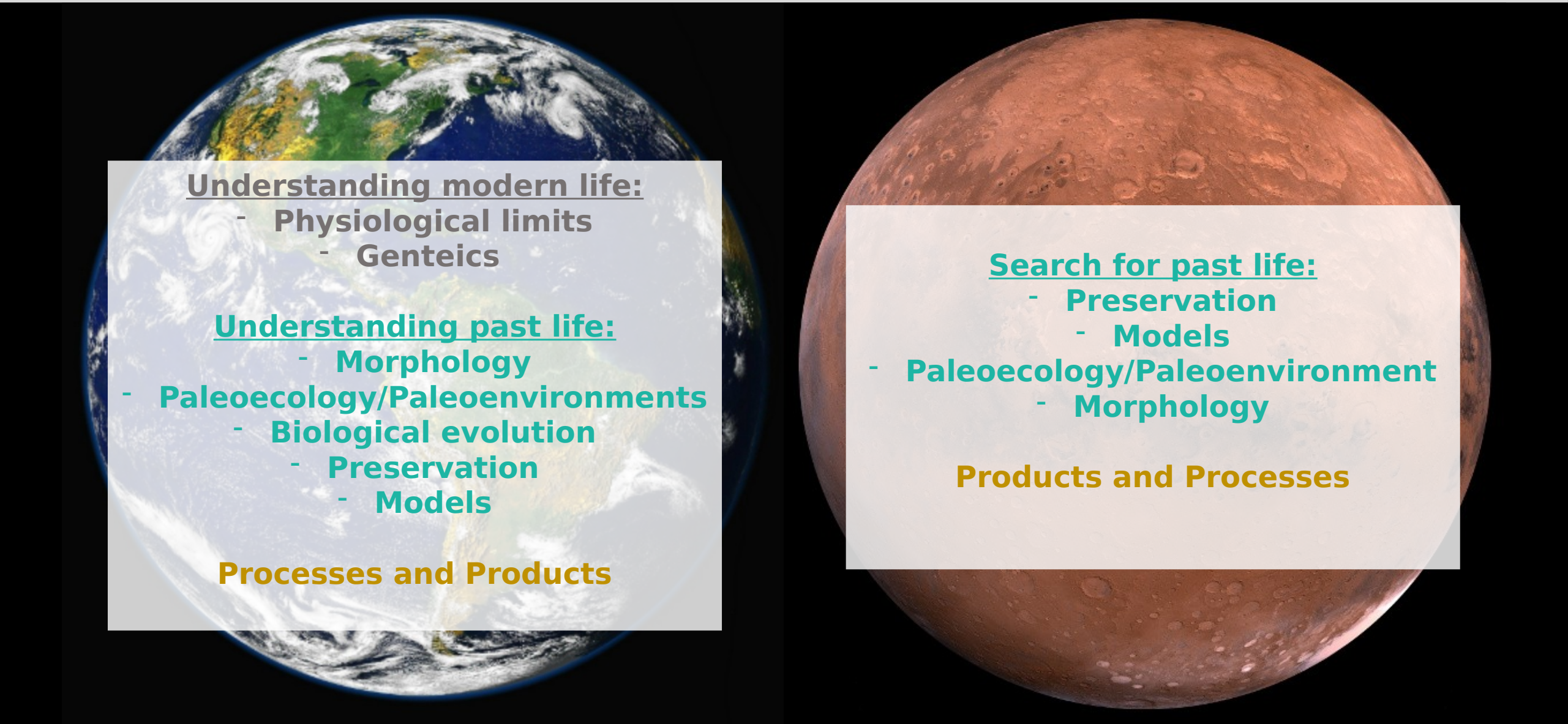
Astrobiology

Paleontology

Astrobiology

Building a bridge between Paleontology and Astrobiology

Conclusion



Understanding modern life:
- Physiological limits
- Genteics

Understanding past life:
- Morphology
- Paleoecology/Paleoenvironments
- Biological evolution
- Preservation
- Models

Processes and Products

Search for past life:
- Preservation
- Models
- Paleoecology/Paleoenvironment
- Morphology

Products and Processes

Recommendation

Clair Patterson and the age of Earth

S01 – E07

Geochimica et Cosmochimica Acta, 1956, Vol. 10, pp. 230 to 237. Pergamon Press Ltd., London

Age of meteorites and the earth

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Division of Geological Sciences
California Institute of Technology, Pasadena, California

(*Received* 23 *January* 1956)

Abstract—Within experimental error, meteorites have one age as determined by three independent radiometric methods. The most accurate method (Pb^{207}/Pb^{206}) gives an age of $4{\cdot}55 \pm 0{\cdot}07 \times 10^9$ yr. Using certain assumptions which are apparently justified, one can define the isotopic evolution of lead for any meteoritic body. It is found that earth lead meets the requirements of this definition. It is therefore believed that the age for the earth is the same as for meteorites. This is the time since the earth attained its present mass.

IT seems we now should admit that the age of the earth is known as accurately and with about as much confidence as the concentration of aluminium is known in the Westerly, Rhode Island granite. Good estimates of the earth's age have been known for some time. After the decay-constant of U^{235} and the isotopic compositions of common earth-leads were determined by NIER, initial calculations, such as GERLING'S, roughly defined the situation. Approximately correct calculations were made by HOLMES and by HOUTERMANS on the basis of bold assumptions concerning the genesis of lead ores. Subsequent criticism of these calculations created an air of doubt about anything concerning common leads and obscured the indispensable contributions which these investigators made in establishing the new science of the geochemistry of lead isotopes. When the isotopic composition of lead from an iron meteorite was determined, we were able to show that a much more accurate calculation of the earth's age could be made, but it still was impossible to defend the computation. Now, we know the isotopic compositions of leads from some stone meteorites and we can make an explicit and logical argument for the computation which is valid and persuasive.

The most accurate age of meteorites is determined by first assuming that meteorites represent an array of uranium-lead systems with certain properties, and by then computing the age of this array from the observed lead pattern. The

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Evolution of Preca
Brazilian geologic

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Lago, 562, Butantã, São Paulo, SP CEP 05508-08

Abstract: Precambrian rocks comprise near

http://journals.cambridge.org/abstract_S1473550412000183

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Thank you!

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