Discussion autour d'une question controversée :

Premières traces de vie avérées ?

Kevin Lepot

kevin.lepot@univ-lille.fr

Université de Lille

LOG

cnrs

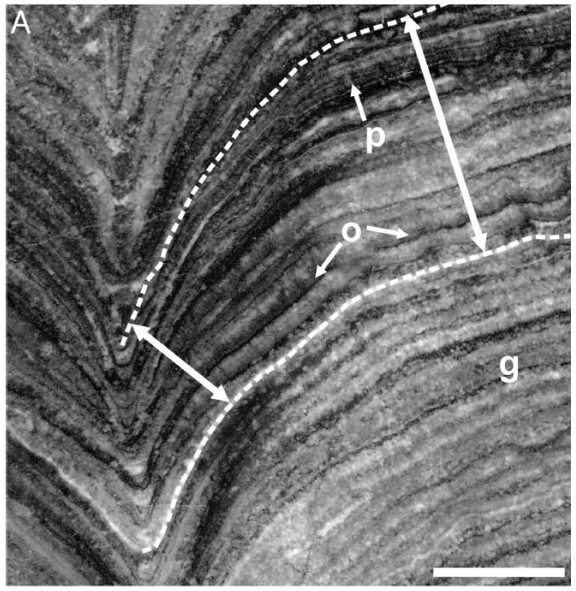
ulco

ANR

M6fossils

Rocks as biosignatures = stromatolites

Stromatolites = laminated rocks (microbial?)



Allwood et al. 2009

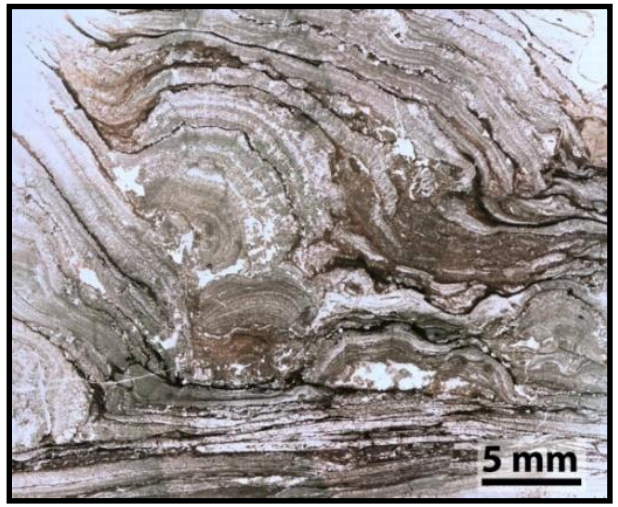
Laminae with
- Complex morphologies
- Organic-rich (dark) laminae

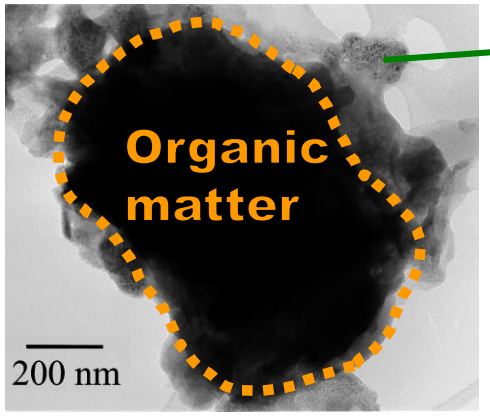
➔ **Reflect growth in presence of microbial mats**

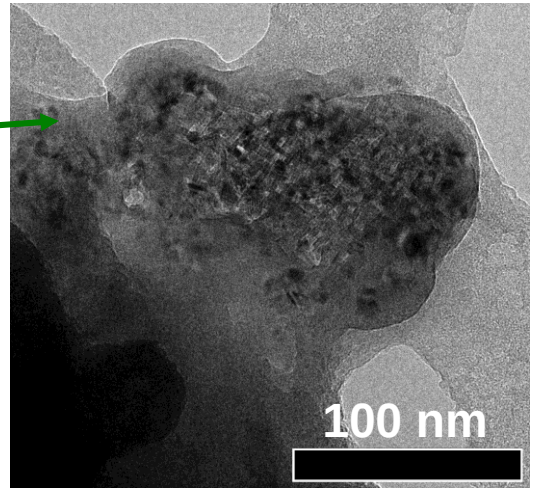
modern mats

Vasconcelos et al. 06

2.72 Ga



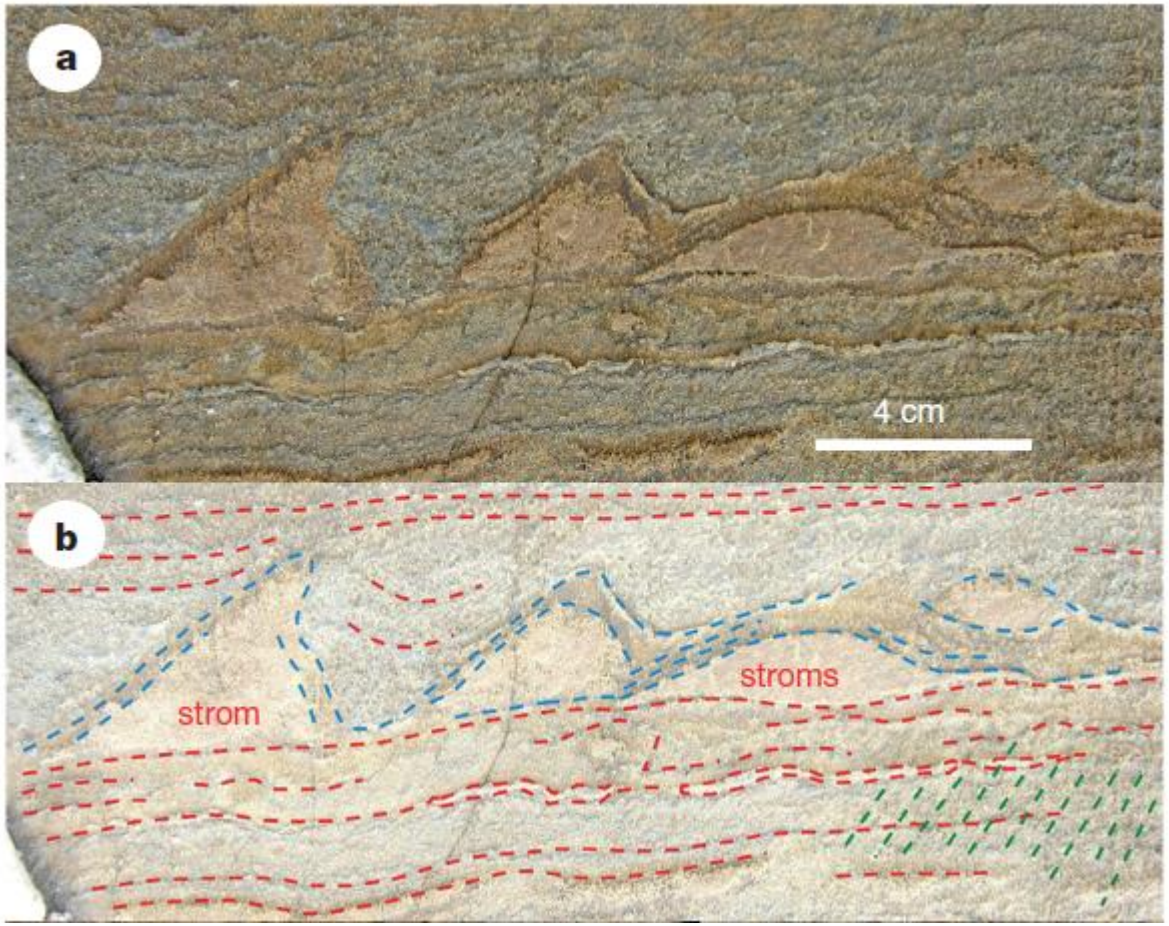




Nanocarbonates in organics
= microbially-induced mineralization?

Lepot et al. 2008

3.7 Ga stromatolites?



Isua, Greenland

Nutman et al. 2016

Laminated dolomites with stromatolite-like cones/domes

Or deformation structures?

Isotope-ratio biosignatures

Metabolism classification

=

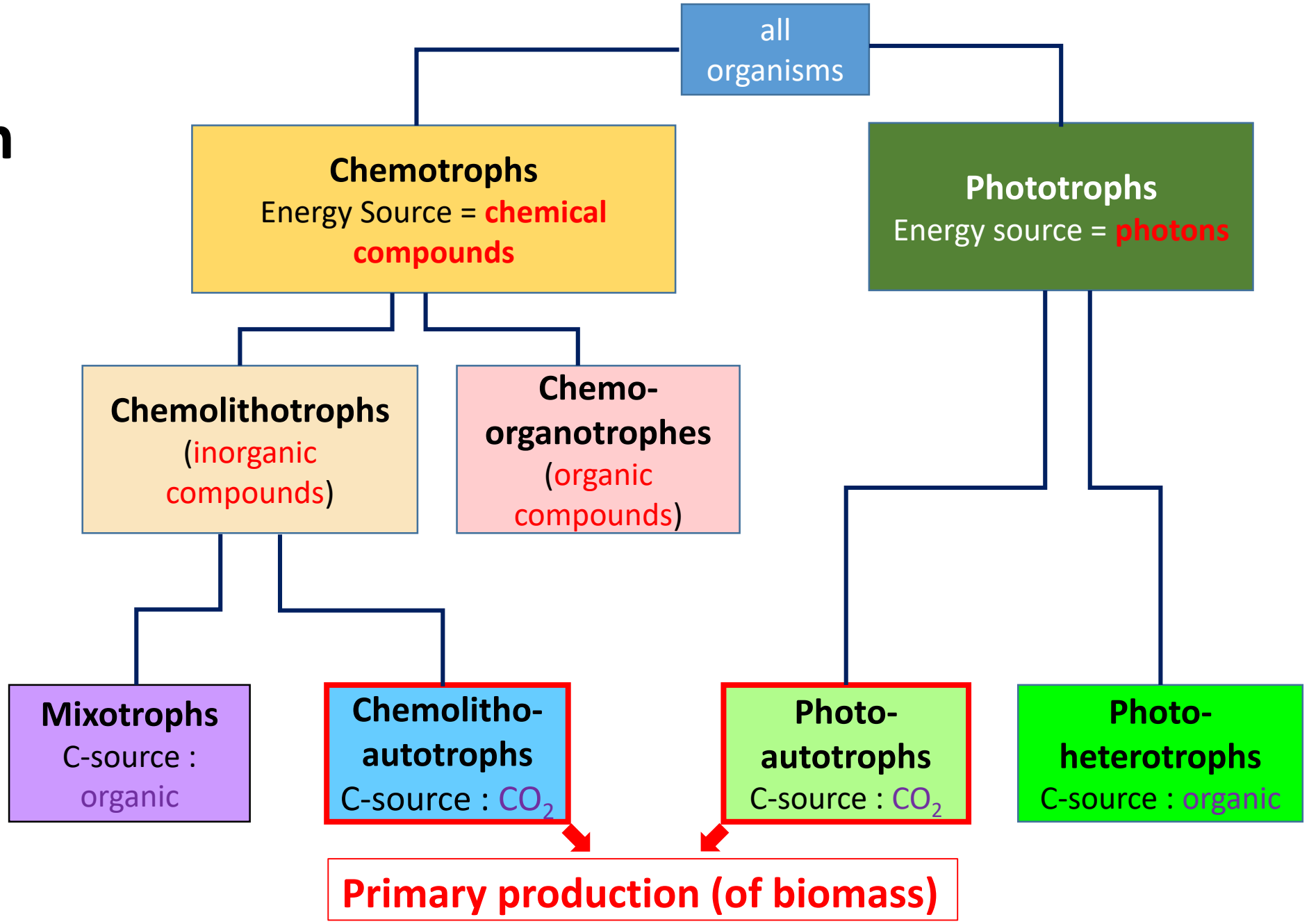
Energy Source

for redox reactions

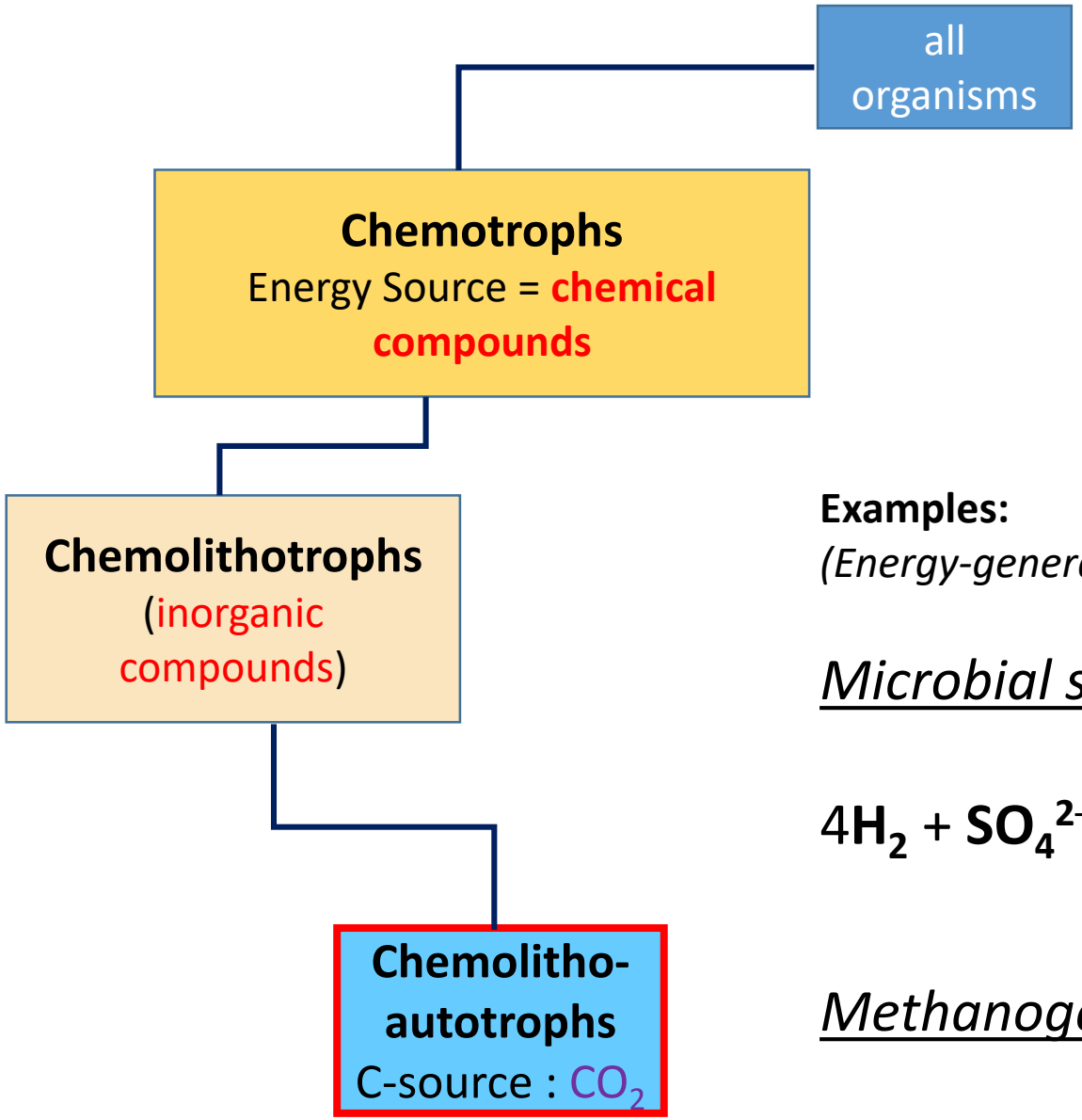
+

Carbon Source

for biomass production



The first primary producers?



Phylog. Tree:
deepest branches of Bacteria & Archaea
= anaerobic chemolithoautotrophs

Examples:
(Energy-generating reaction of metabolism)

Microbial sulfate reduction

$$4\mathbf{H_2} + \mathbf{SO_4^{2-}} \rightarrow \mathbf{H_2S} + 2H_2O + 2OH^-$$

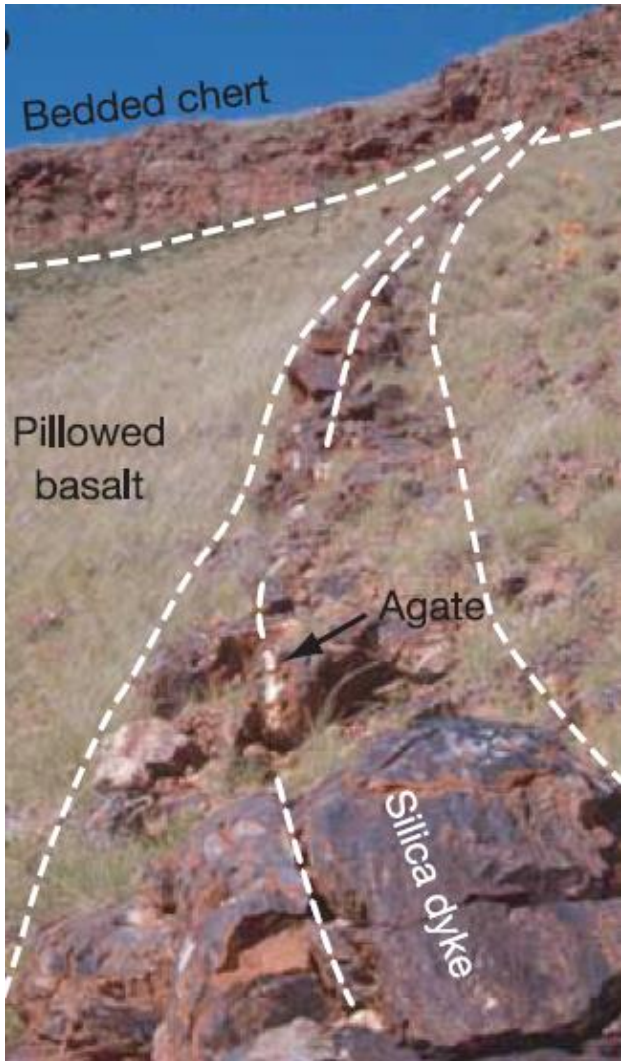
Methanogenic archaea

$$4\mathbf{H_2} + \mathbf{CO_2} \rightarrow \mathbf{CH_4} + 2H_2O$$

Methanogenesis at 3.5 Ga?

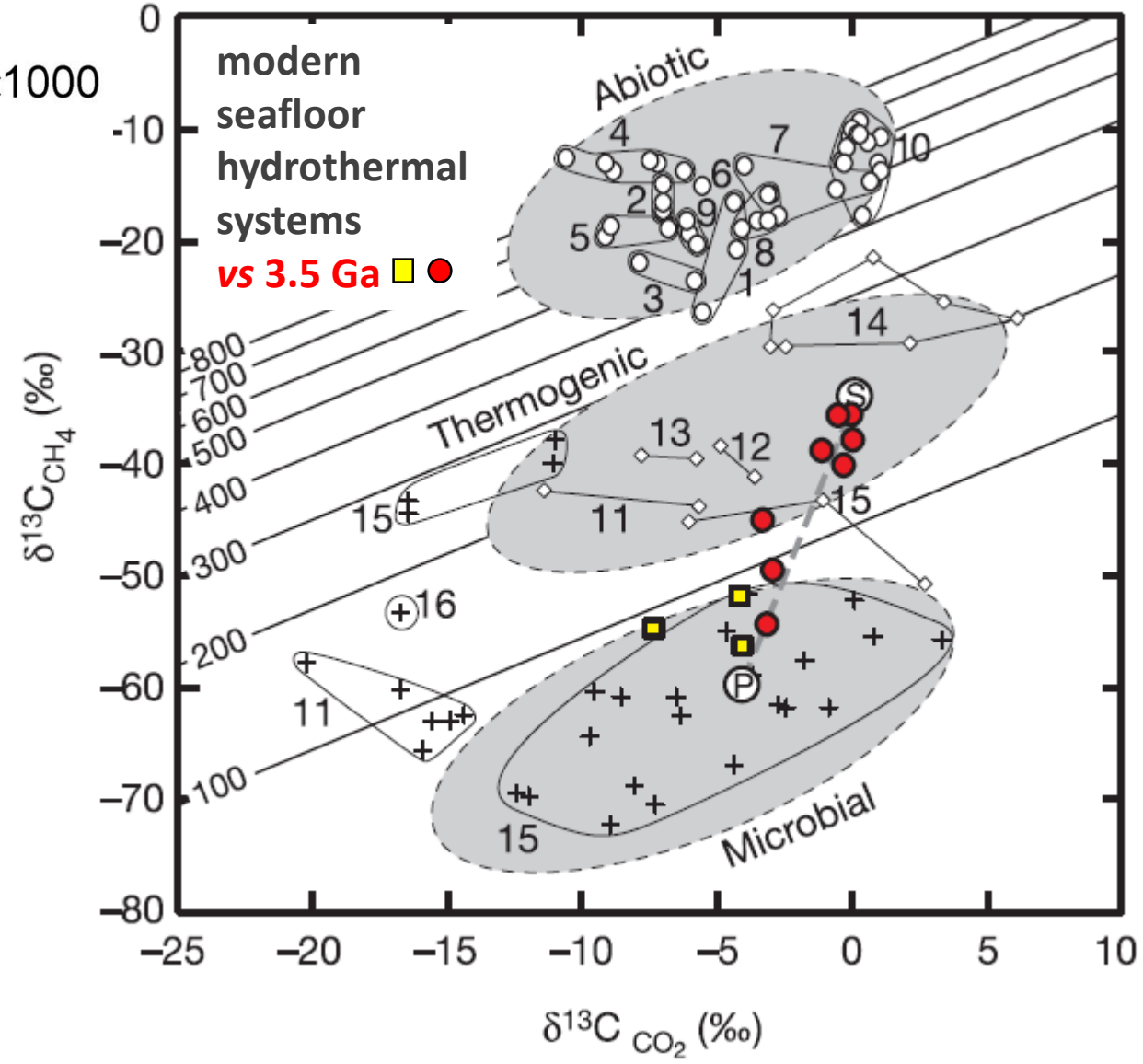
$$\delta^{13}C = \left[\frac{^{13}C/^{12}C}{^{13}C/^{12}C_{ST}} - 1 \right] \times 1000$$

ST : standard



$\delta^{13}C$ of CO_2 & CH_4 in fluid inclusions in hydrothermal cherts

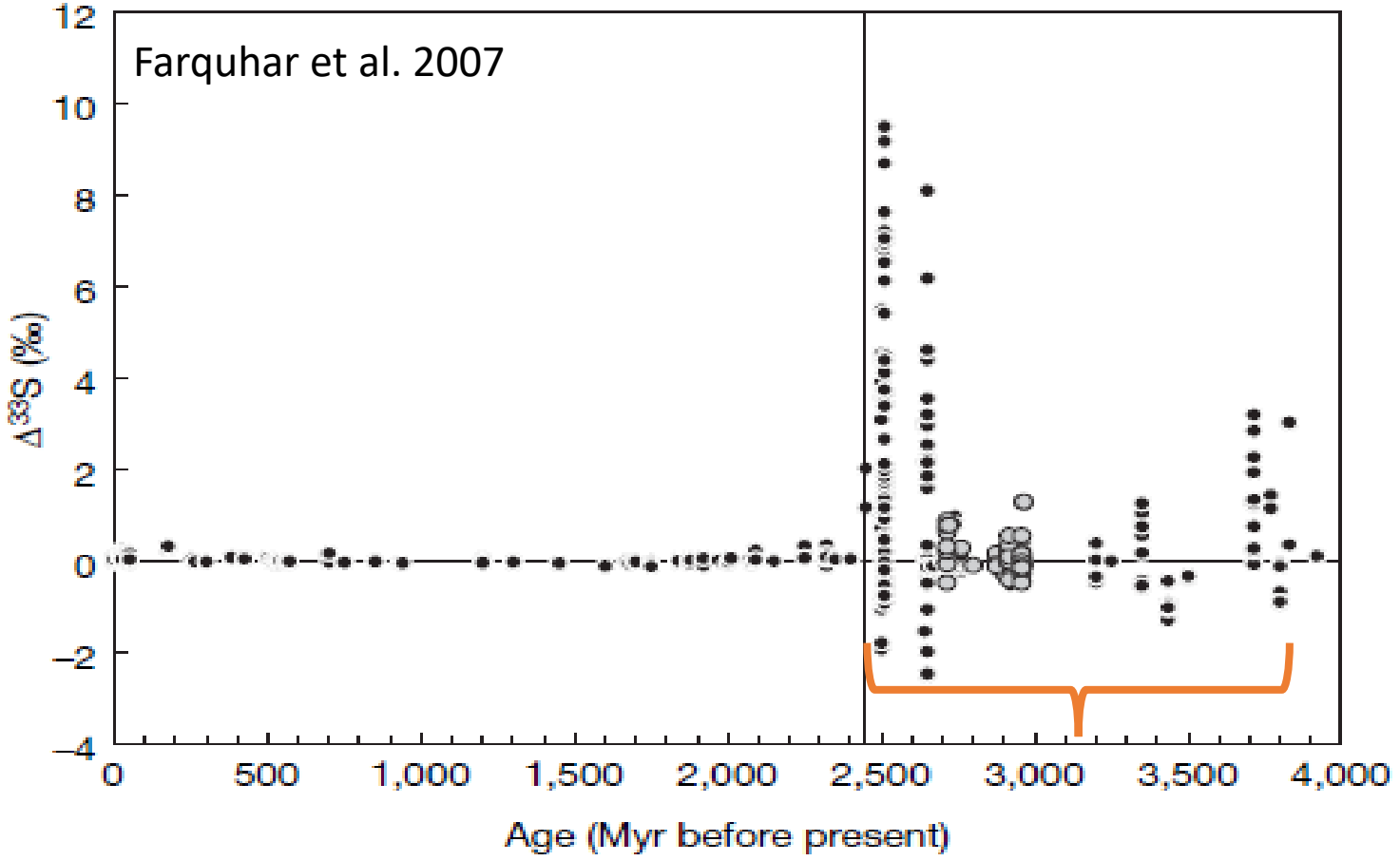
Ueno et al. 2006



BUT: abiotic hydrothermal reactions may form similar $\delta^{13}C$ values

Sherwood Lollar & McCollom 2006

S-isotope record ➔ ≈no atmospheric O_2 before 2.4 Ga



$\Delta^{33}S \neq 0$ before 2.4 Ga

formed by:

$SO_2 \xrightarrow{UV} S^0 + H_2SO_4$

- in ozone-free atmosph.
- **at very low pO_2 only**

$\delta^X S = 1000.[(^X S/^{32}S)_{sample}/ (^X S/^{32}S)_{std} - 1]$ X = 33, 34, 35

$\delta^{34}S = \delta^{33}S / 0.515$: proportionnal to ^{32}S-^{33}S mass difference ➔ mass-dependant fractionation

$$\Delta^{33}S = \delta^{33}S - 1000 \times \left[\left\{1 + \frac{\delta^{34}S}{1000}\right\}^{0.515} - 1\right]$$ ≠0 ➔ mass-independant fractionation

$\Delta^{33}S$ - $\Delta^{36}S$ trend ➔ microbial SO_4^{2-} reduction @ 3.5 Ga

$$\Delta^{33}S = \delta^{33}S - 1000 \times \left[\left\{ 1 + \frac{\delta^{34}S}{1000} \right\}^{0.515} - 1 \right]$$

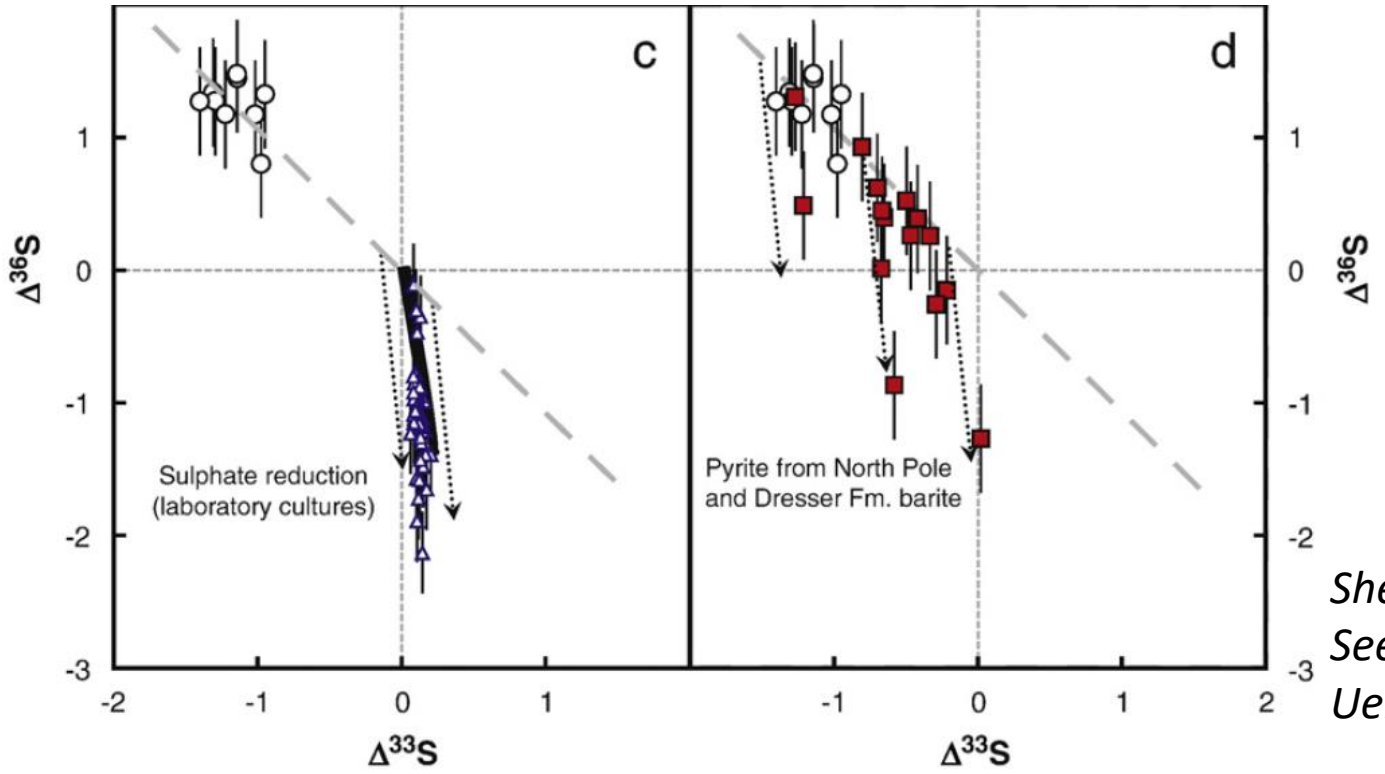
and

$$\Delta^{36}S = \delta^{36}S - 1000 \times \left[\left\{ 1 + \frac{\delta^{34}S}{1000} \right\}^{1.90} - 1 \right].$$

Metabolism:

SO_4^{2-} + orga
<u>and/or</u> **$H_2 \pm CO_2$**

➔ **HS^- + biomass**



Shen et al. 2009
See also
Ueno et al. 2009

Photosynthetic primary production in the Archean?

Bacterial domain of the phylogenetic tree

$CO_2 + H_2O \rightarrow [CH_2O]$ (orga matter) $+ O_2$

Oxygenic photosynthesis

Anoxygenic photosynthesis
→ Before oxygenic

1. $2H_2 + CO_2 \rightarrow [CH_2O] + H_2O$
2. $H_2S + 2CO_2 + 2H_2O \rightarrow 2[CH_2O] + SO_4^{2-} + 2H^+$
3. $4Fe^{2+} + CO_2 + 11H_2O \rightarrow [CH_2O] + 4Fe^{III}(OH)_3 + 8H^+$

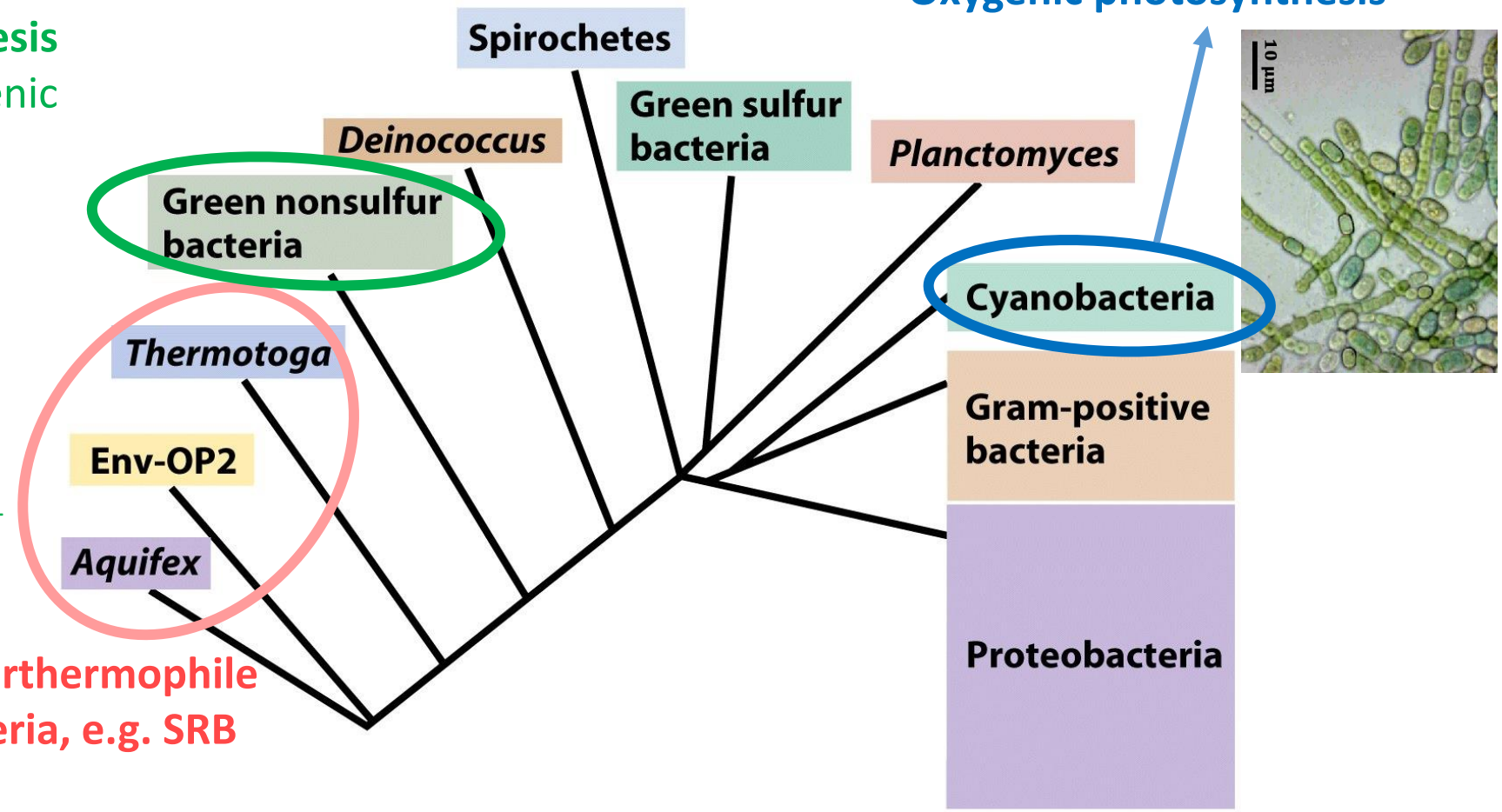
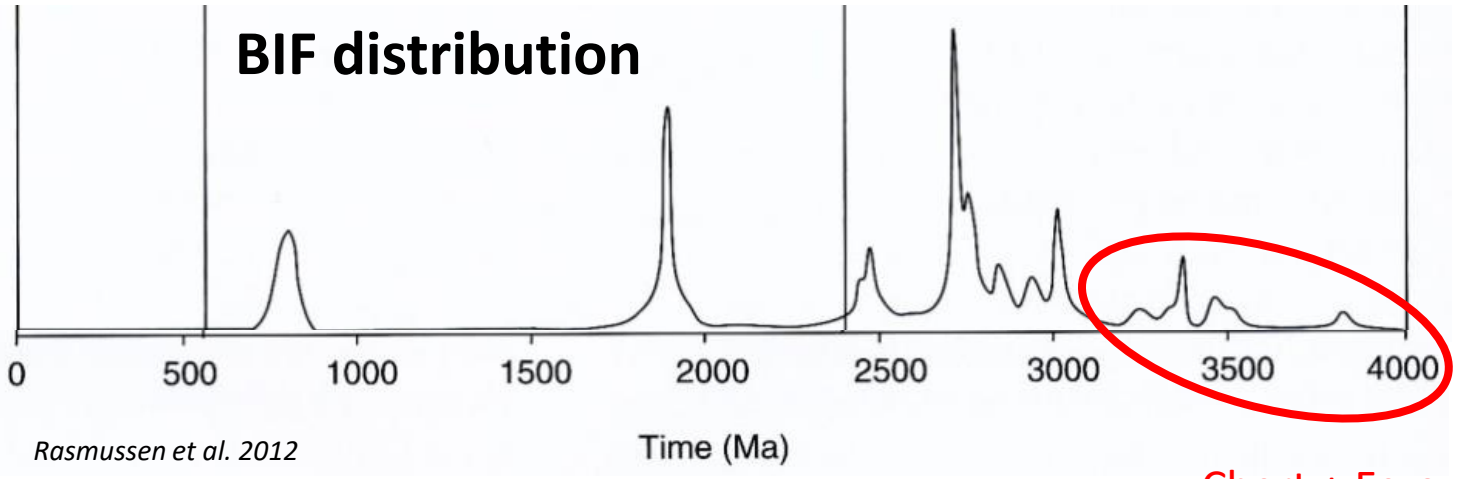


Figure 2-9 Brock Biology of Microorganisms 11/e
© 2006 Pearson Prentice Hall, Inc.

Anoxygenic photosynthesis in the early Archean?



Rasmussen et al. 2012

Chert + Fe-oxides BIF

3.46 Ga *Marble Bar* BIF

Banded Iron Formations

Origin of Fe^{3+} in oxides ?

A $4Fe^{2+} + CO_2 + 11H_2O \rightarrow [CH_2O] + 4Fe^{III}(OH)_3 + 8H^+$

anoxygenic photosynth ?

B Oxidation of Fe^{2+} by/using O_2 / $NO_{2/3}^-$?

C Late (<2.7 Ga?) oxidation by meteoric O_2 ?

Fe isotopes

$$\delta^{i}_{j}Fe = \left[\frac{^{i}Fe/^{j}Fe}{^{i}Fe/^{j}Fe_{ST}} - 1 \right] \times 1000$$

i = 56, 57, 58
j = 54

1) δ^{56}Fe +1.5 to +2.6‰
➔ Primary oxidation of small fraction of Fe^{2+}-reservoir

2) Low [U] ➔ reduced environment

3.46 Ga *Marble Bar* BIF

Suggest Fe-oxidation by anoxygenic photosynthesis, not O_2, @ 3.46 Ga

Li et al. 2013 GCA

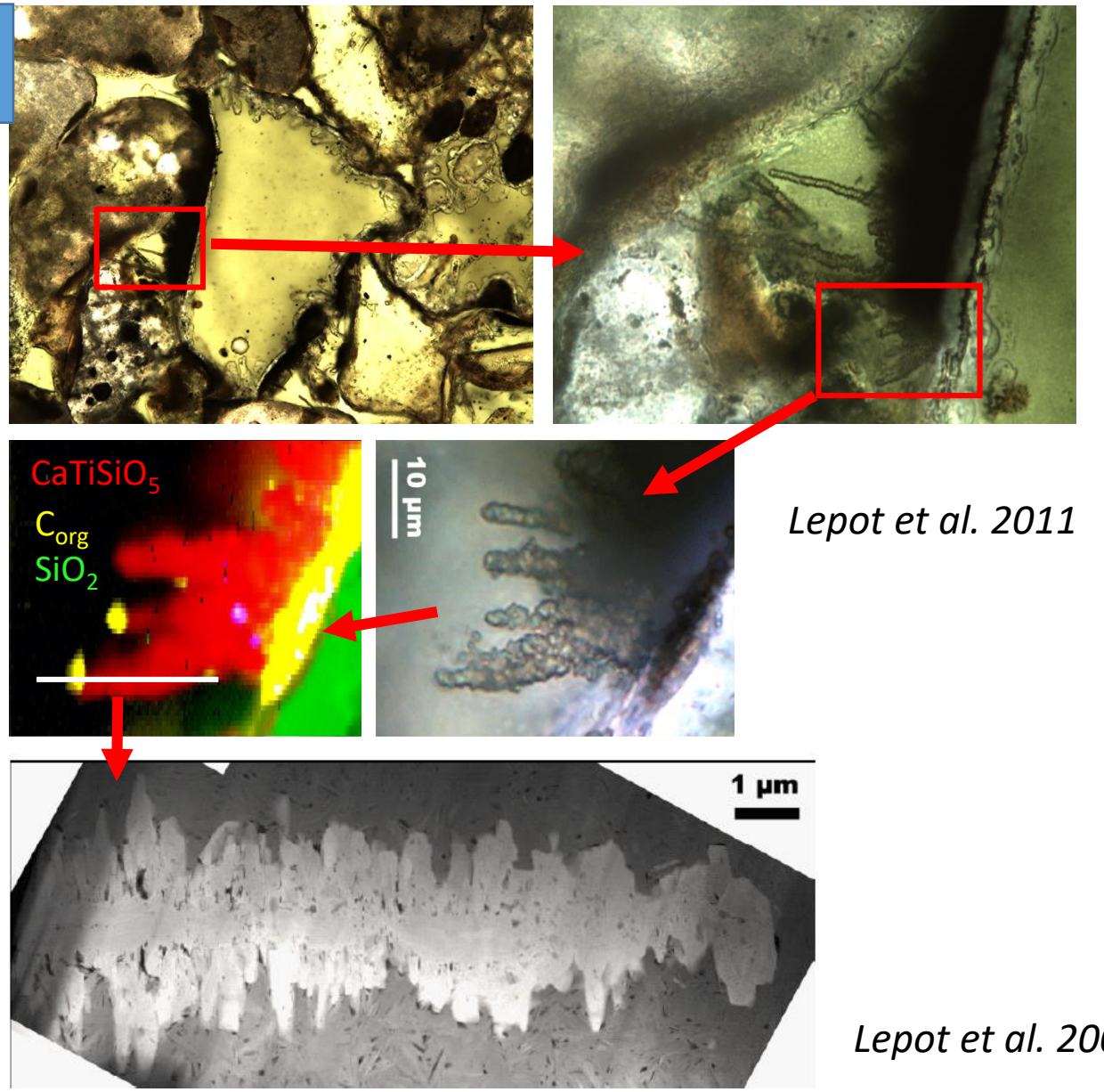
Mineral µ-structures = biosignatures?

- Microbial dissolution borings?
- Molds of microfossils?
- Abiotic?

Endolithic microtubes formed by dissolution of basaltic glass ?

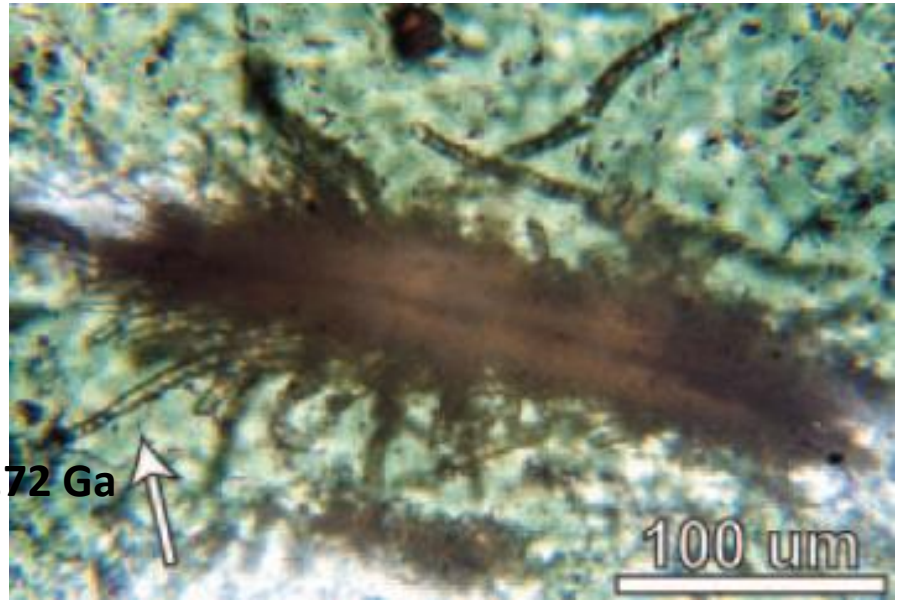
versus

Metamorphic dendrites formed in (crystalline) cements



Lepot et al. 2011

Lepot et al. 2009, 2011

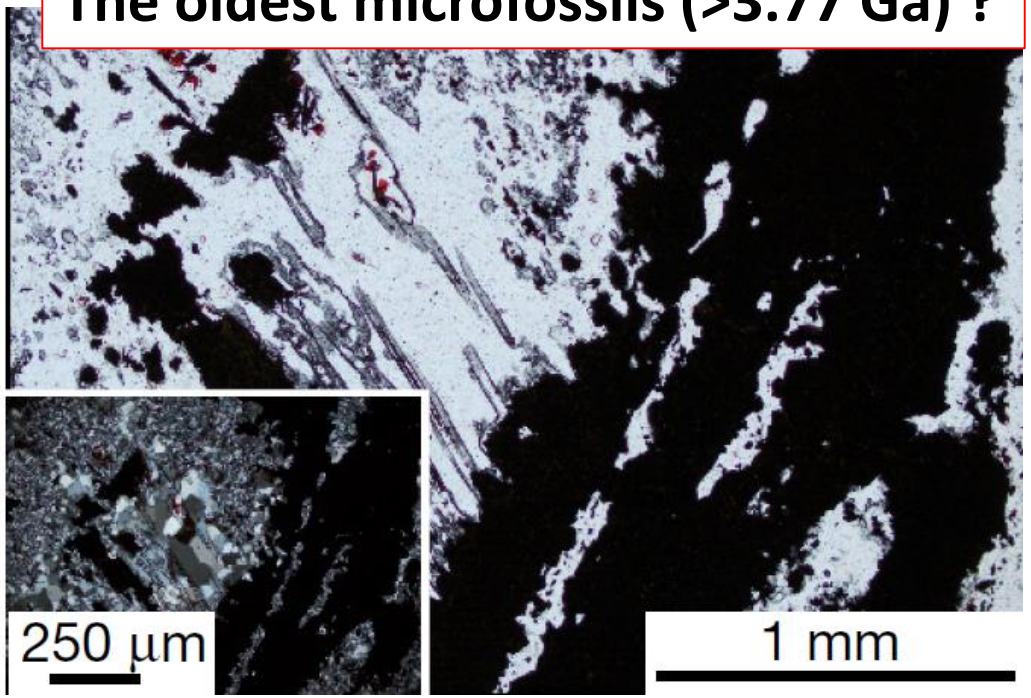


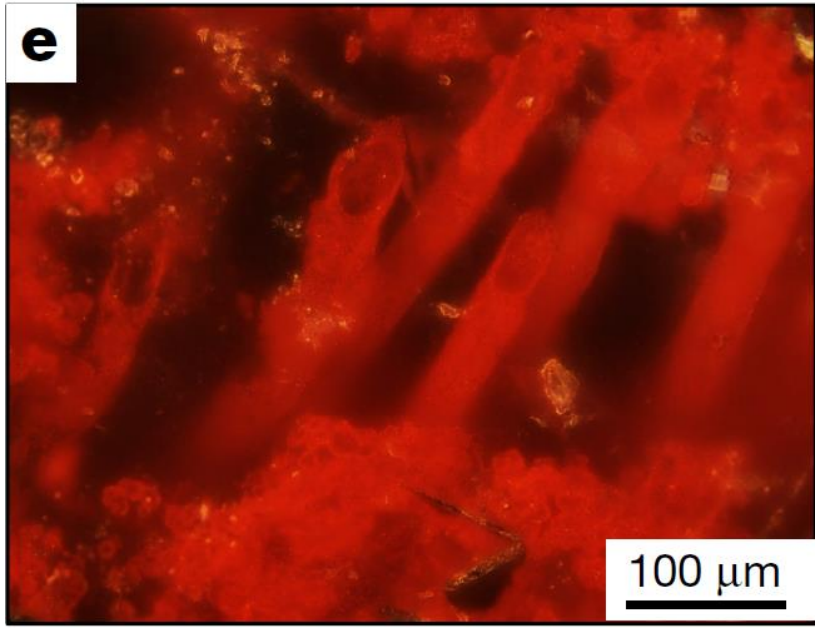
$CaTiSiO_5$ tubes **~3.5 Ga**

Furnes et al. 2004

Metamorphic mineral!

The oldest microfossils (>3.77 Ga) ?





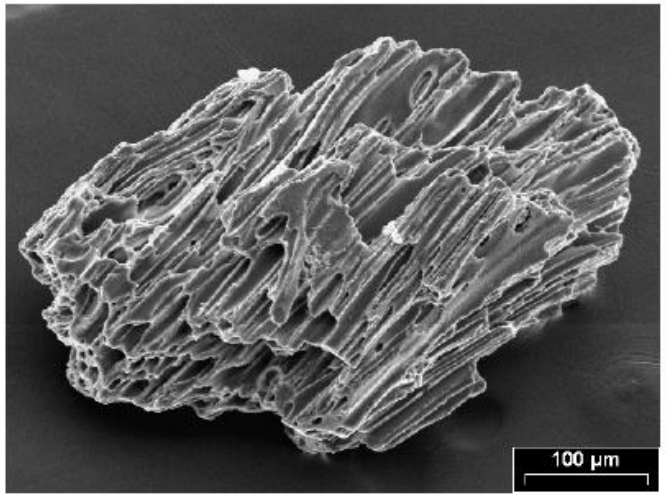
Dodd et al. 2017

Fe-oxide microtubes

<u>No carbon relic!</u>

versus

Volcanic textures ?



Daga et al. (pipe vesicles)
in volcanic ash

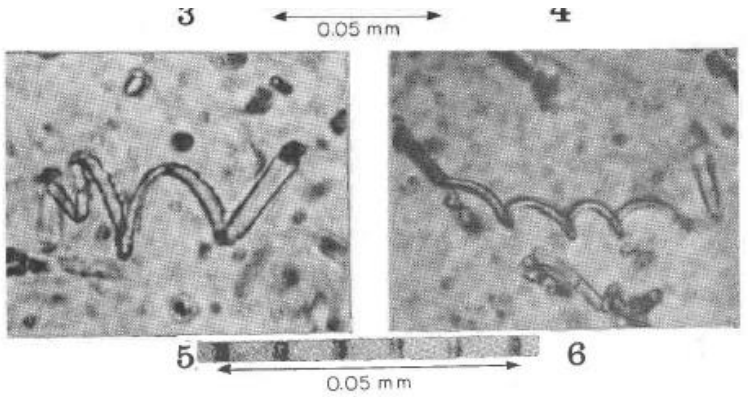
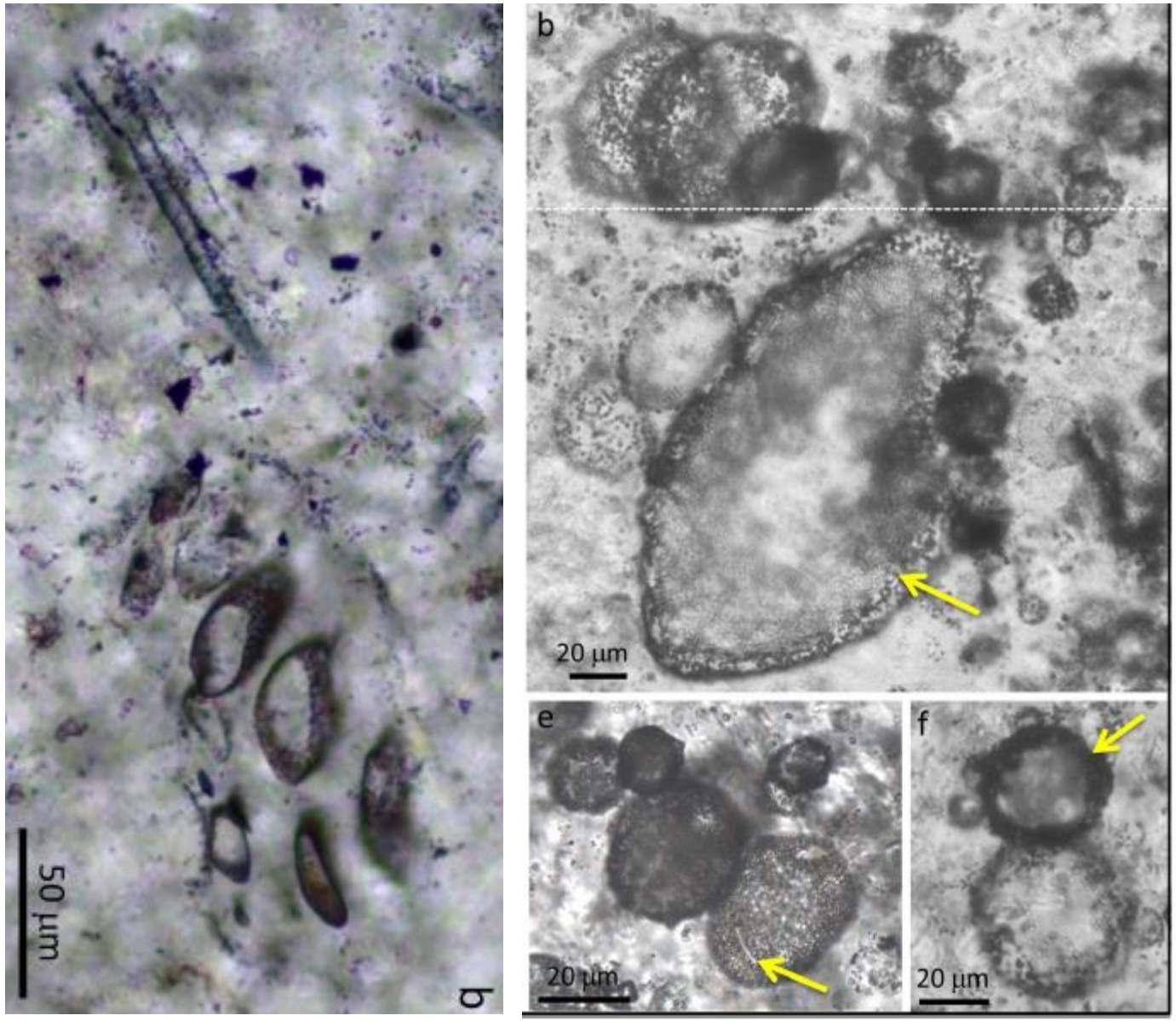


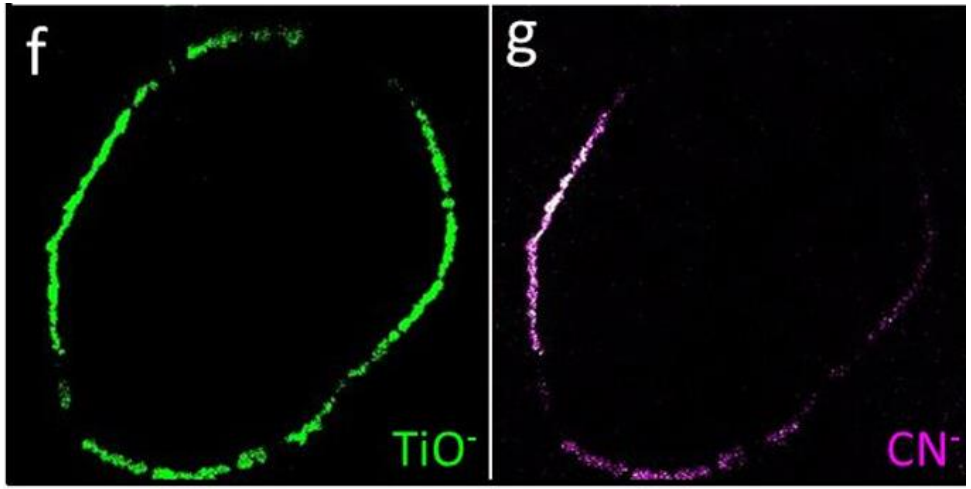
FIG. 3. Sanidine and amphibole microlites.

Ross et al. 1962
(microlithes)

~3.4 Ga microfossils re-evaluated as magmatic vesicles



Some coated with organic carbon!



➔ Mimic microfossils!

Wacey et al. 2018

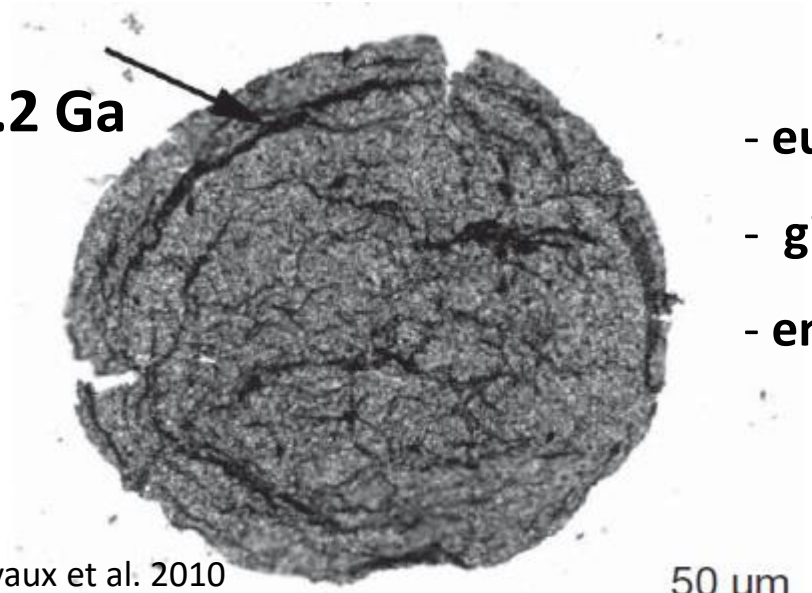
Organic µ-structures = cellular microfossils ?

1.88 Ga « Gunflint » microfossils

Cyanobacteria? (Lepot et al. 2017)

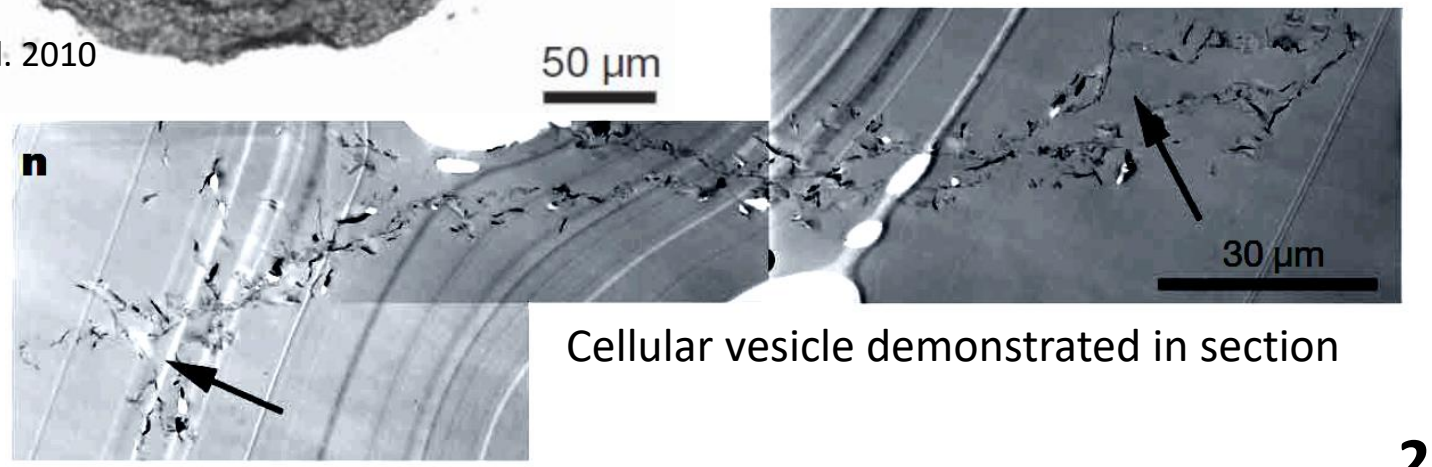
Archean (2.5 – 4 Ga) microfossils

3.2 Ga

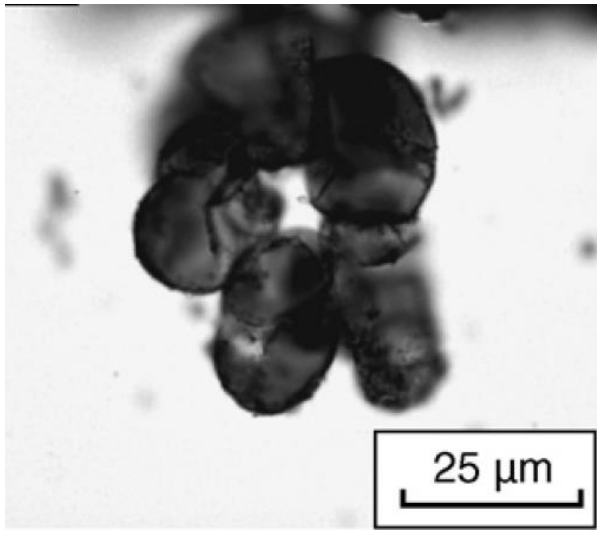


Javaux et al. 2010

- **eukaryote ?**
- **giant bacteria?**
- **enveloppe of « colonial » bacterial?**

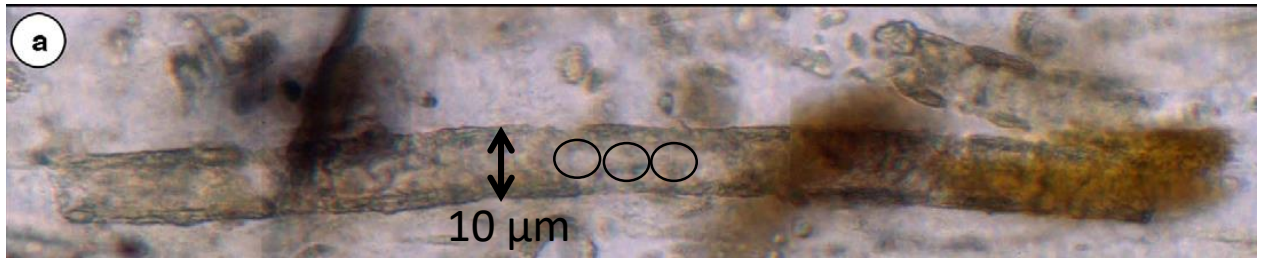


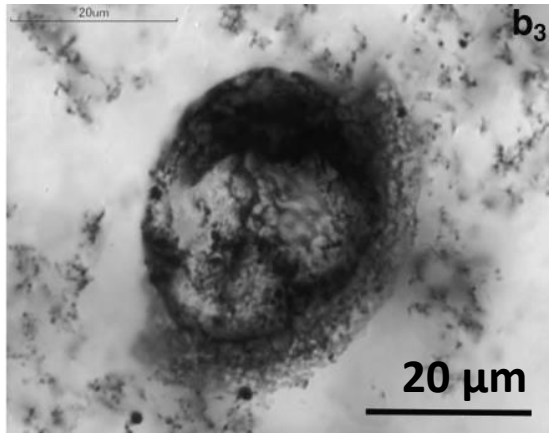
Cellular vesicle demonstrated in section

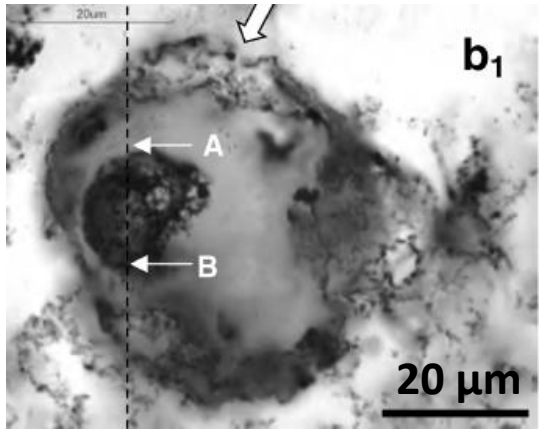


3 Ga Grey et al. 2009

2.5 Ga Klein et al. 1981



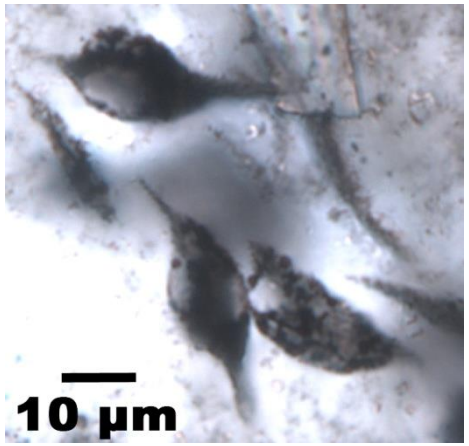


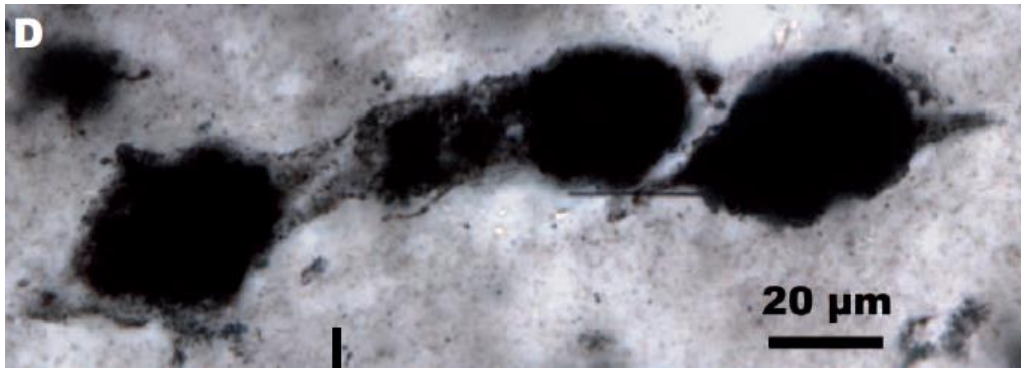


Sugitani et al. 2009

3.0 Ga

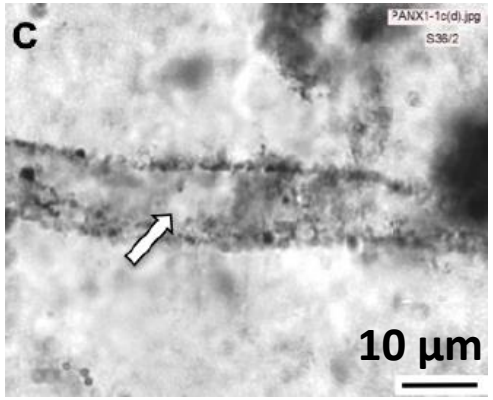
Unidentified Archean microfossils

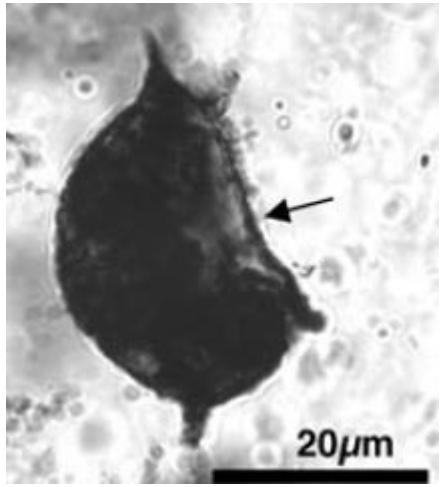


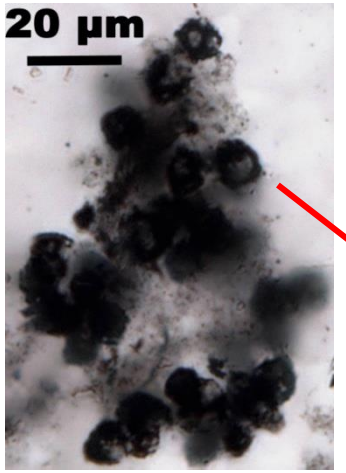


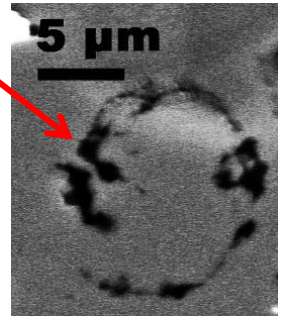
3.4 Ga

Strelley Pool Formation



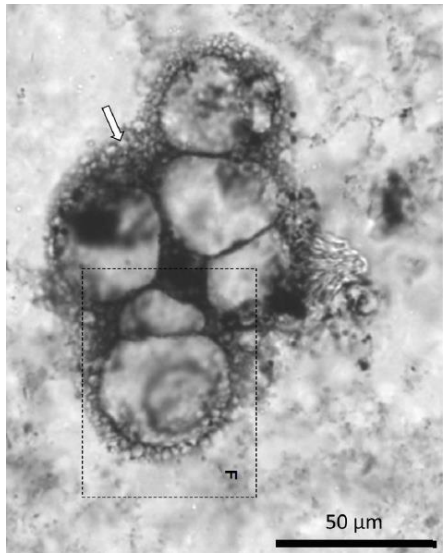


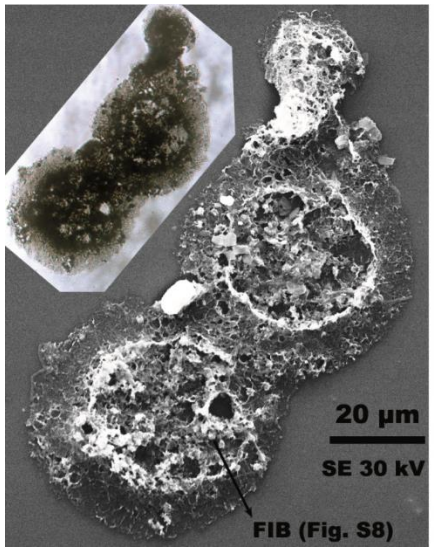


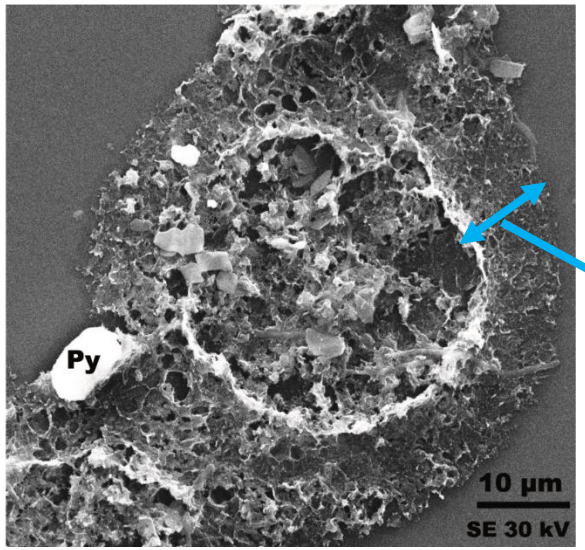


Sugitani et al. 2010; 2012, 2015, 2018
Lepot et al. 2013

3.4 Ga lenticular microfossils with equatorial flange





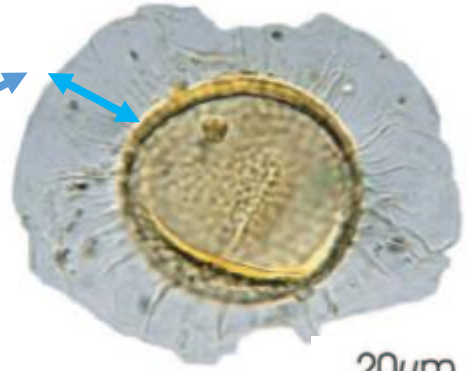


flange

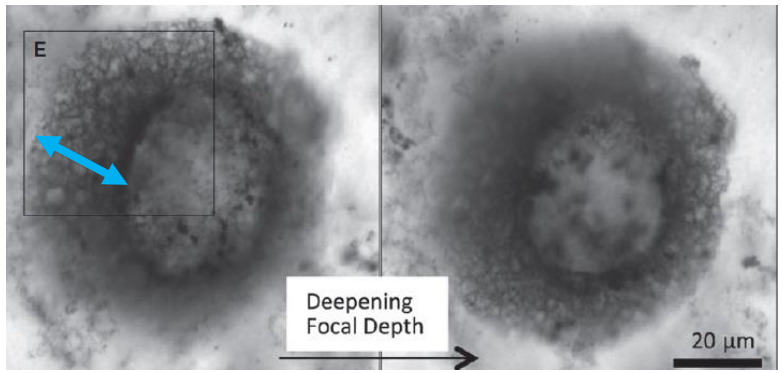
Silurian prasynophyte algae

?

?

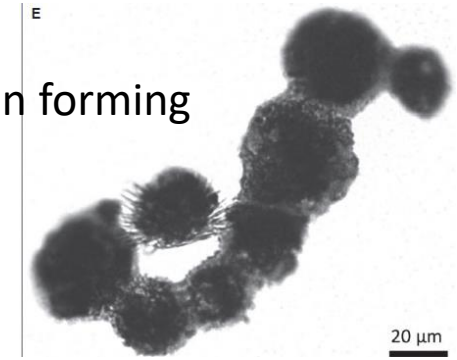


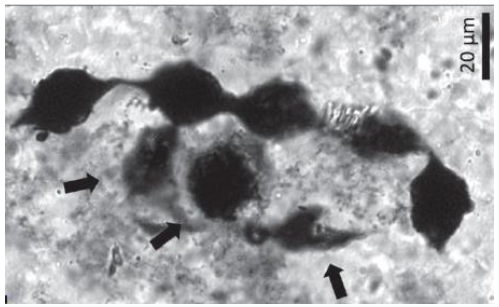
Le Hérissé et al. 2009

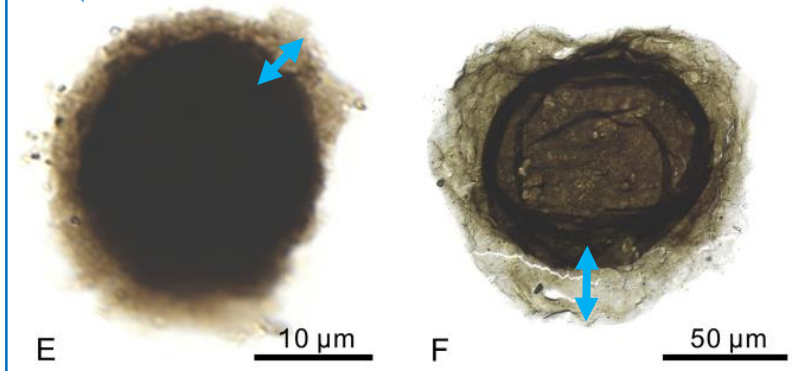


Apparent cell wall structure

Chain forming







900—750 Ma Microfossils

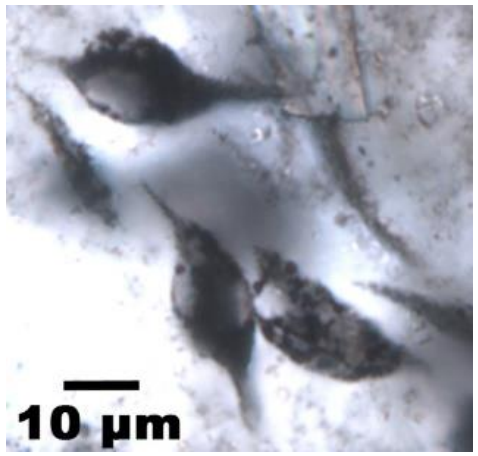
Tang et al. 2013

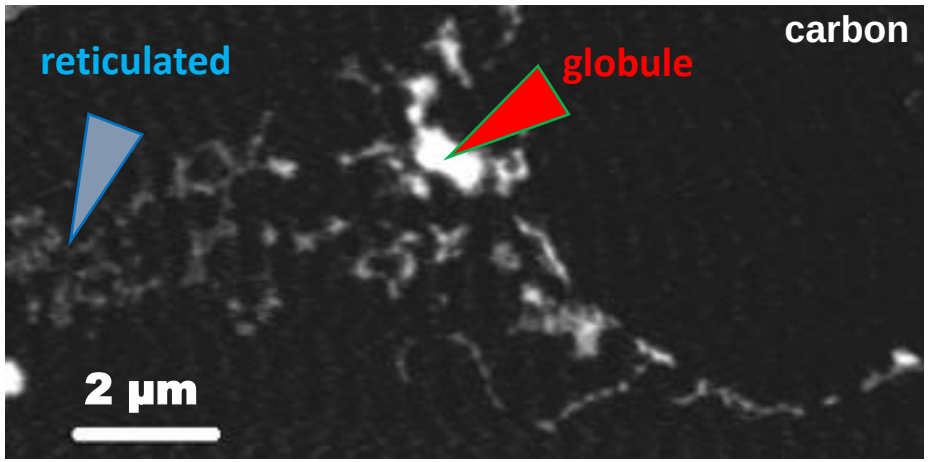
Strelley Pool Formation

Sugitani et al. 2015a, 2015b

Heterogenous molecule µ-reservoirs in 3.4 Ga cells?

Strelley Pool Formation



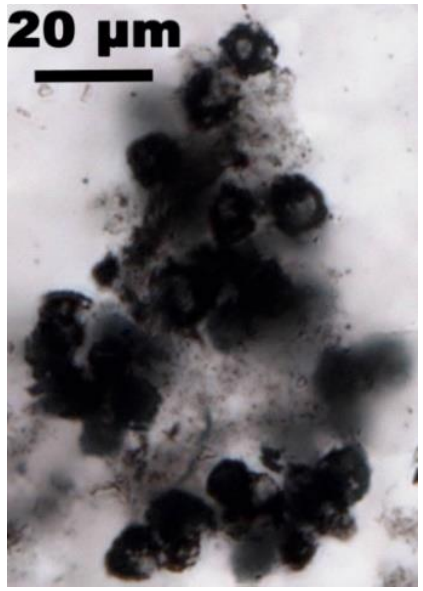


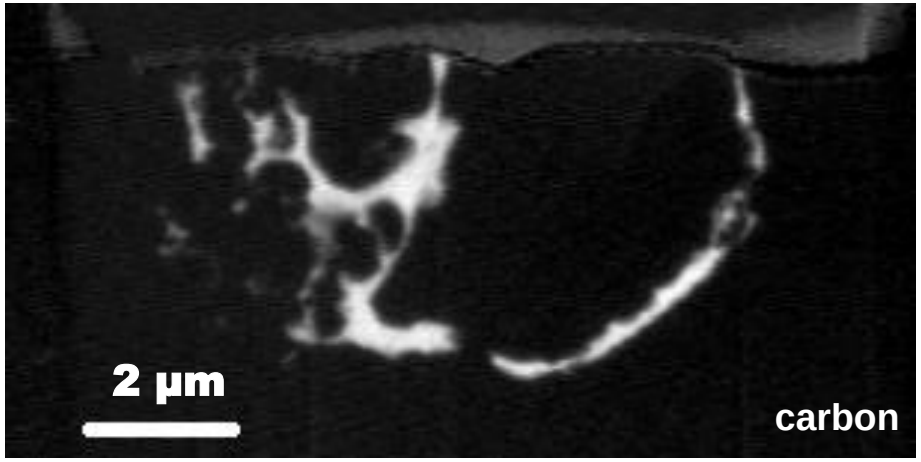
Lenses:

- Reticulated organics
  $\delta^{13}C$ = -32 ‰
  ➔ polysaccharides?

- globules down to - 40 ‰
  ➔ lipids?

Support selective preservation of specific biomolecules in microfossils





Spheres:

- thick capsule:
  polysaccharides?

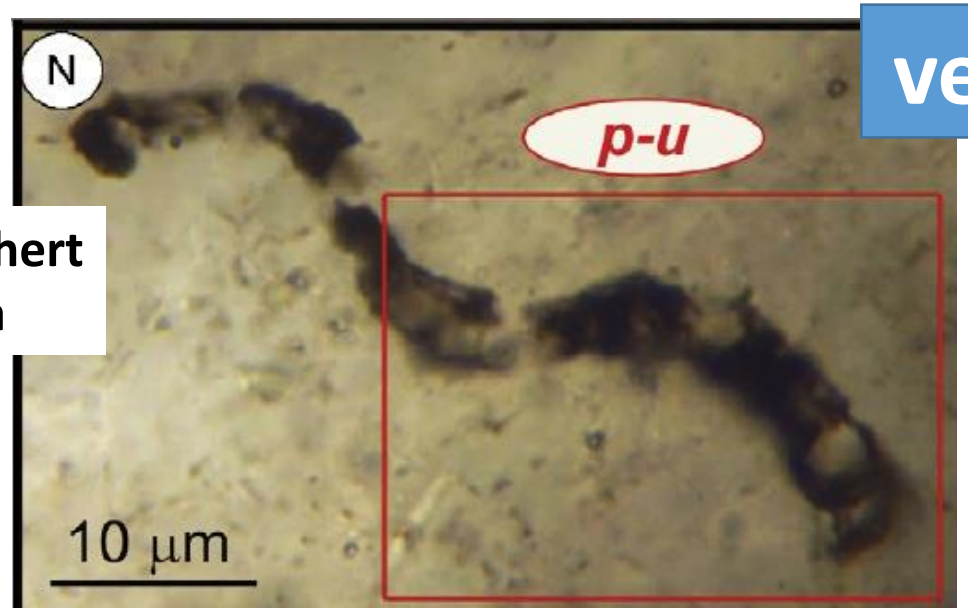
$\delta^{13}C$ = -36 ‰
➔ different metabolism?

The oldest organic microfossils?

cell-like organic coatings?

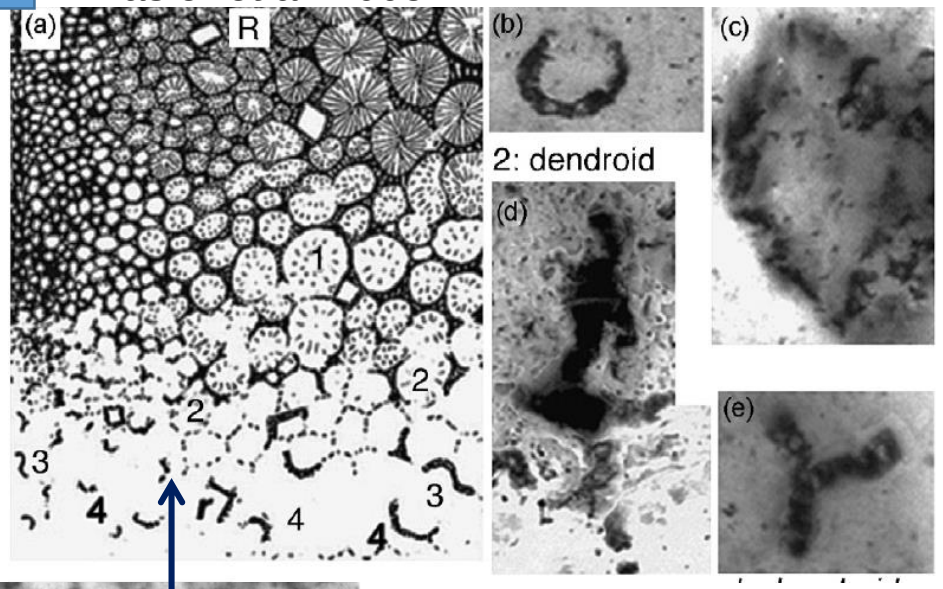
versus

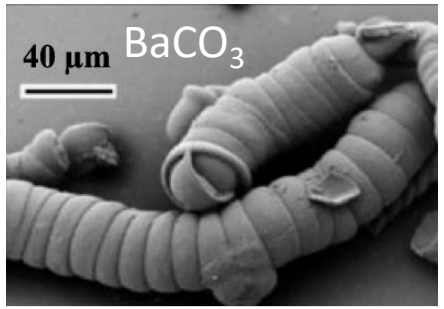
Apex Chert
3.46 Ga



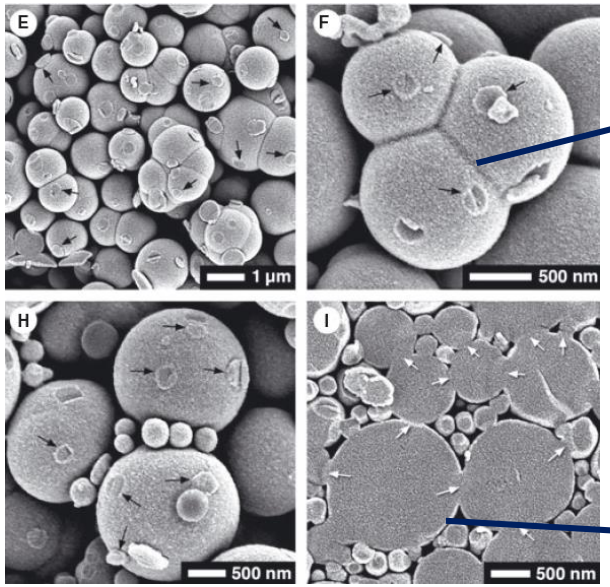
Schopf et al. 2009

Other cell-like forms in the same rock:
Brasier et al. 2005

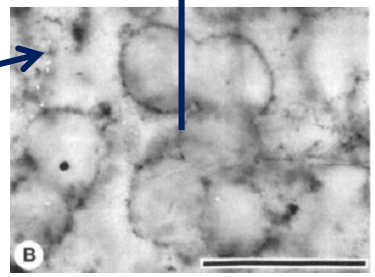




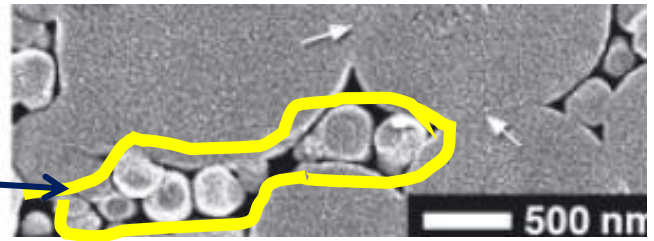
Garcia-Ruiz 03



Opal
(abiotic SiO_2)

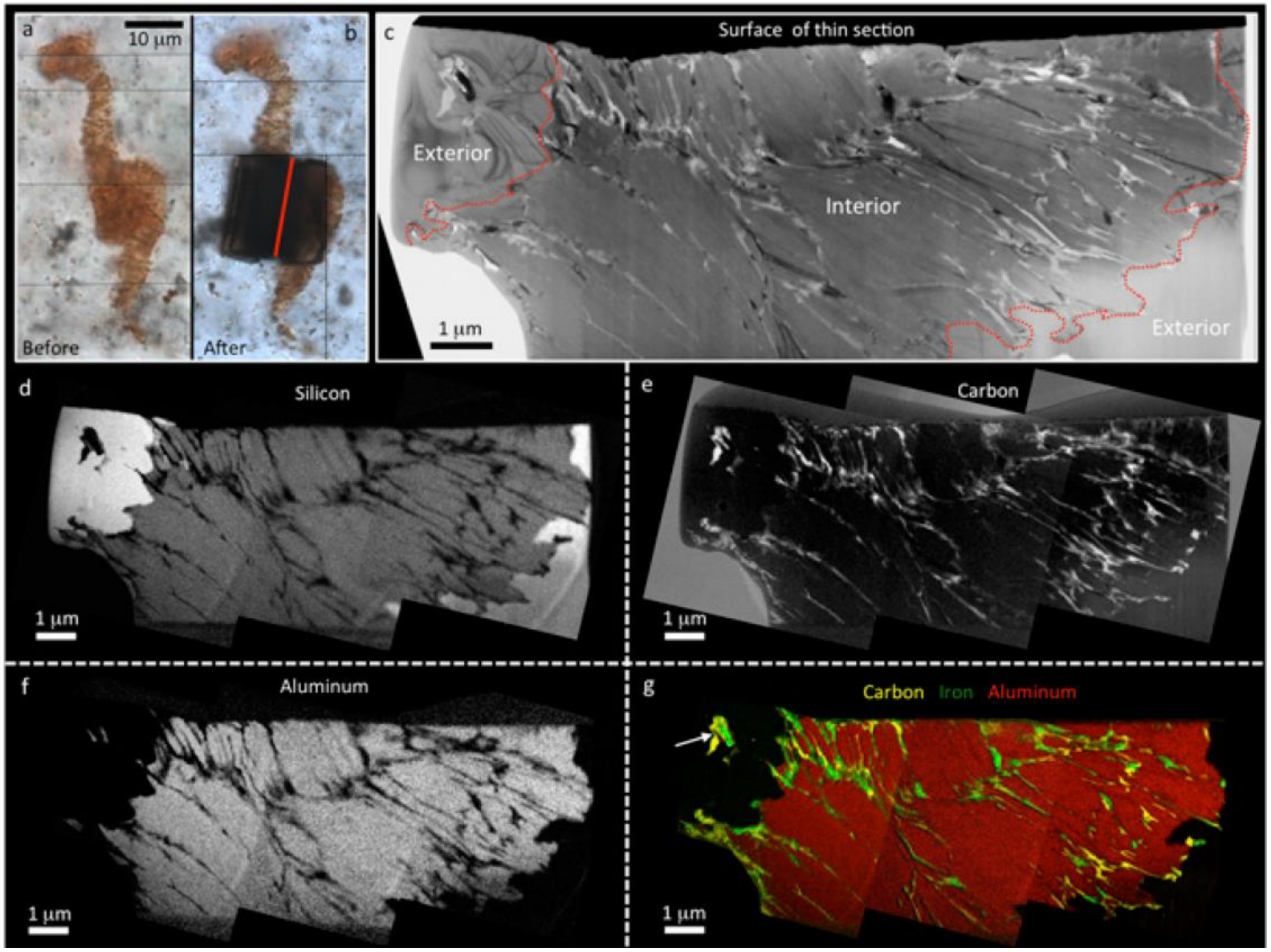


Opal coated by organic matter
(3.5 Ga) Buick 1990



Jones & Renaut 07

Apex (3.46 Ga) microfossils? in chert



= vermiform
micas
interlayered with
bitumen?

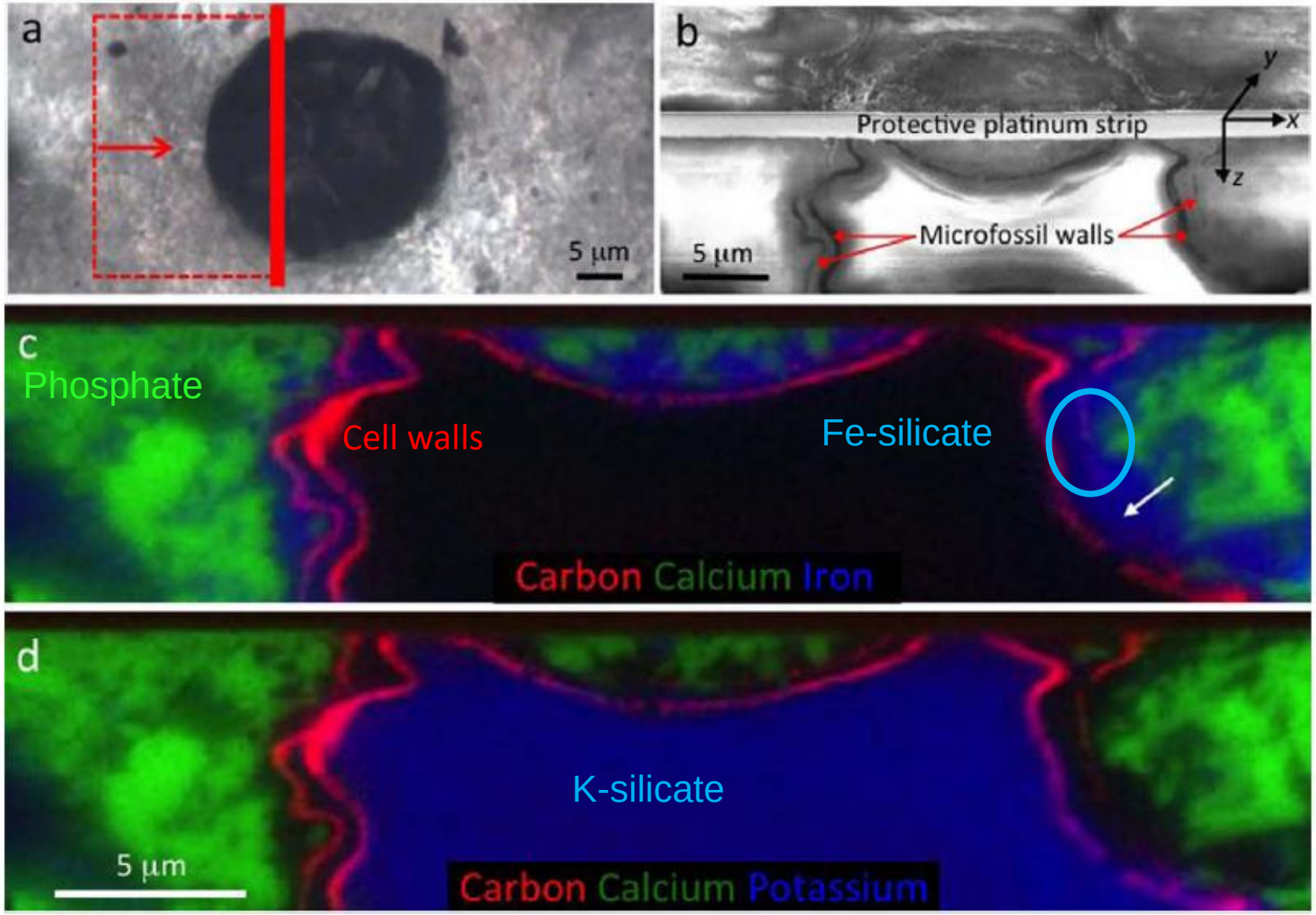
Brasier et al. 2015

or =

true microfossils with
internal fossilization by clays
(see next slide)

+ local redistribution of
organic matter ?

Post-mortem clays in true microfossils!

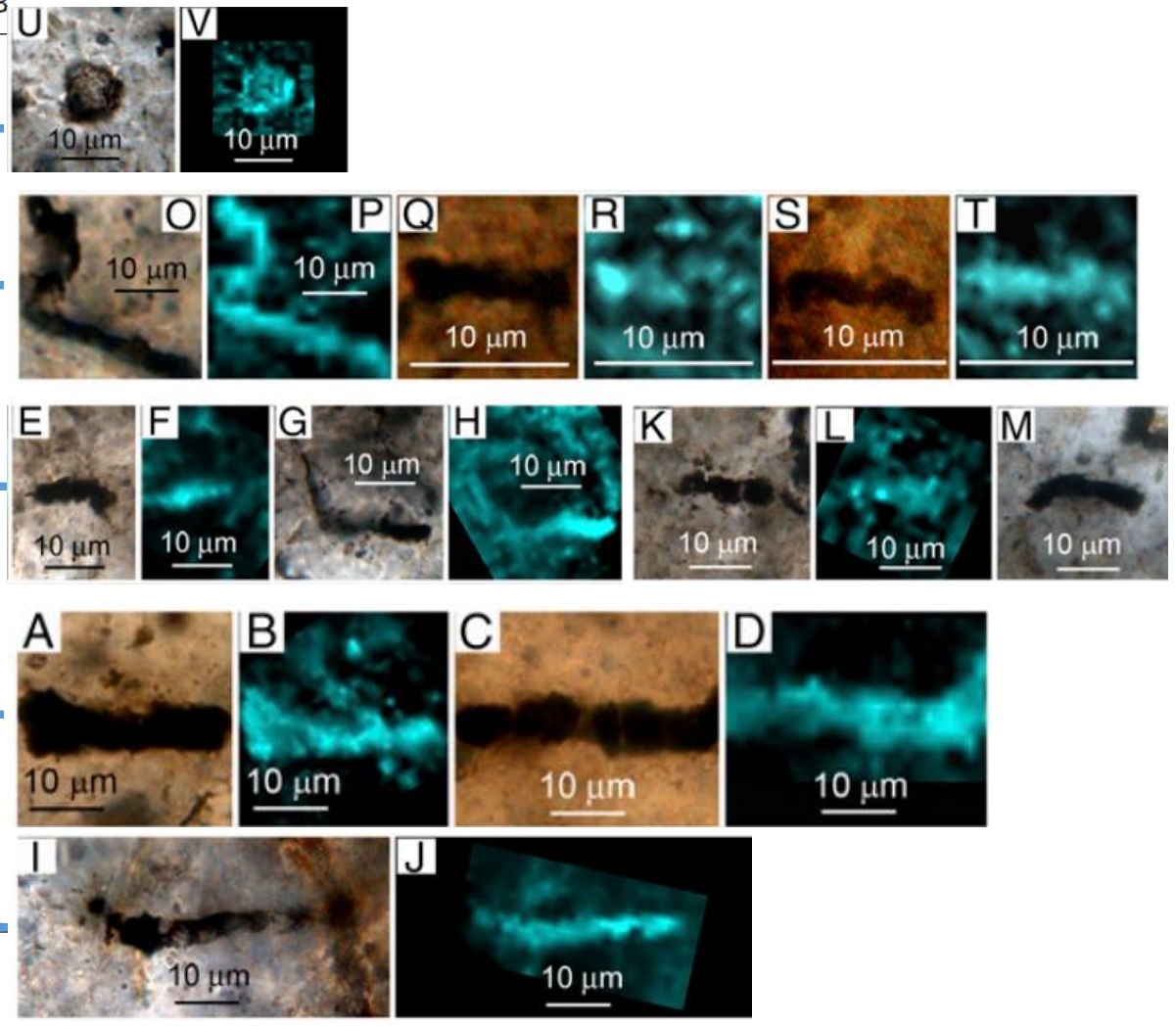


1 Ga microfossils

Wacey et al. 2014

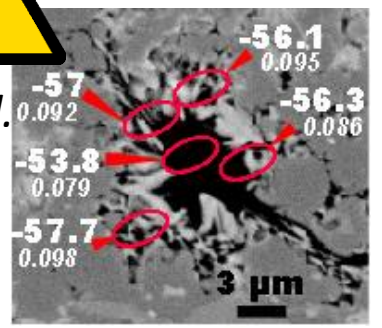
Morphospecies-correlated C-isotope composition in Apex chert ‘microfossils’

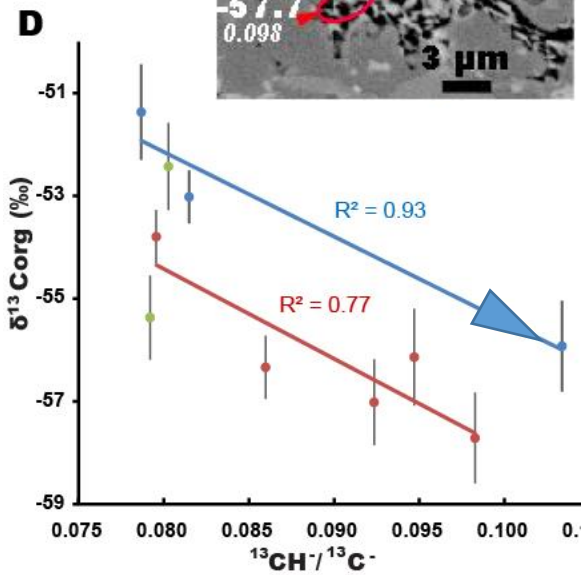
Taxon (specimen)	$\delta^{13}C$‰ VPDB
Unnamed unicell	
(Clast #12)	−30.9
	−30.9
Avg.	
P. minutum	
(Clast #9)	−34.1†
(Small clast #2)	−30.9
(Small clast #3)	−29.8
	−31.6
Avg.	
P. delicatulum	
(Clast #4)	−32.7
(Clast #5)	−38.2
(Clast #6)	−36.9
(Clast #11)	−33.6
	−35.4
Avg.	
A. disciformis	
(Specimen #F)	−41.7
(Specimen #F)	−44.1‡
(Specimen #G, Session-1)	−32.6†
(Specimen #G, Session-2)	−38.5§
	−39.2
Avg.	
P. amoenum	
(Specimen #H)	−39.4
	−39.4
Avg.	



Schopf et al. 2017

Lepot et al. in press





Bias on $\delta^{13}C$ by clays

Brasier et al 2015

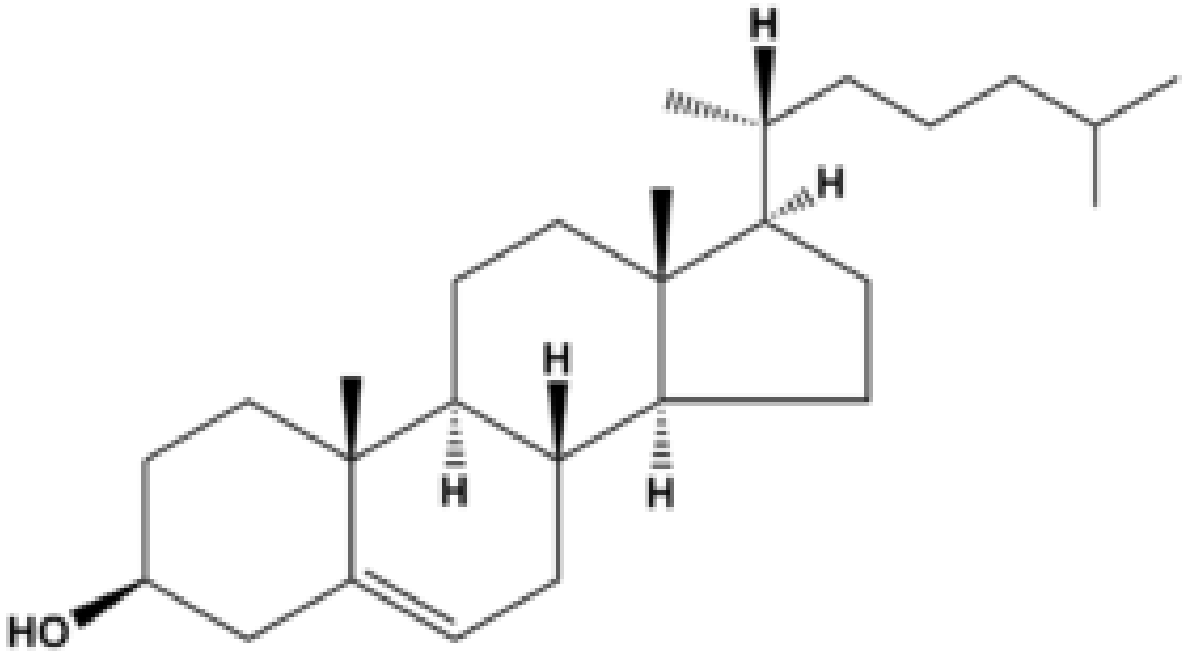
➔clays in « microfossils »

➔ to check!

Molecular bio signatures

- Extractible biomarkers?
- Composition of microfossils?

The biomarker problem



Cholesterol

diagnostic molecules derived from lipids
preserved for ~1.6 Ga

(Brocks et al. 2005)

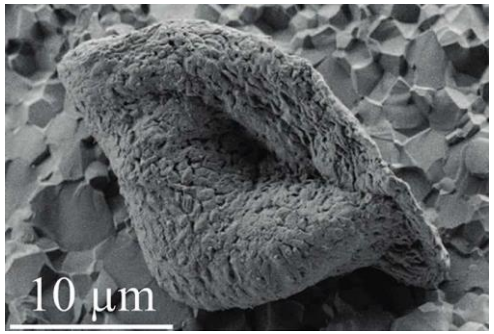
Lipid biomarkers in ~2.7 Ga rocks
➔ re-assessed as contaminants

(French et al. 2013)

Functional group composition in 3.4 Ga microfossils

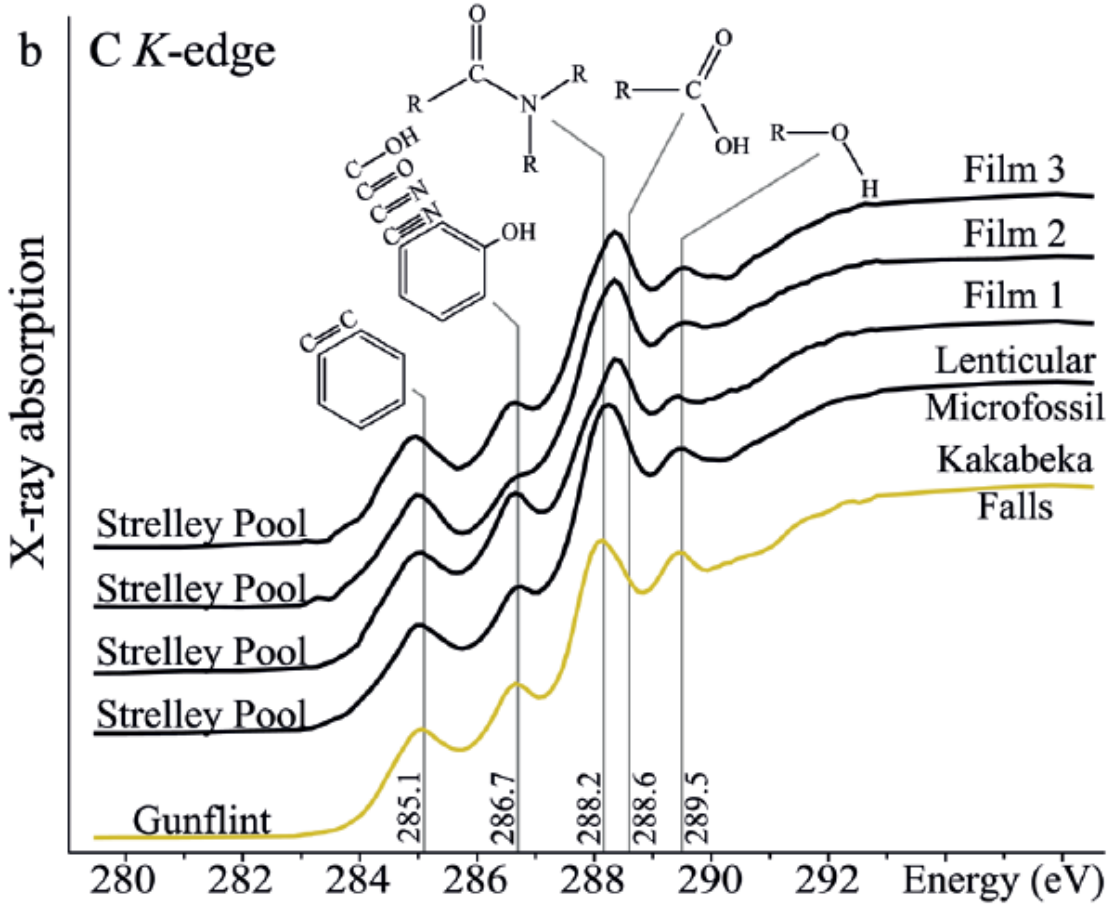
➔ similar to « reference » microfossils, 1.9 Ga Gunflint

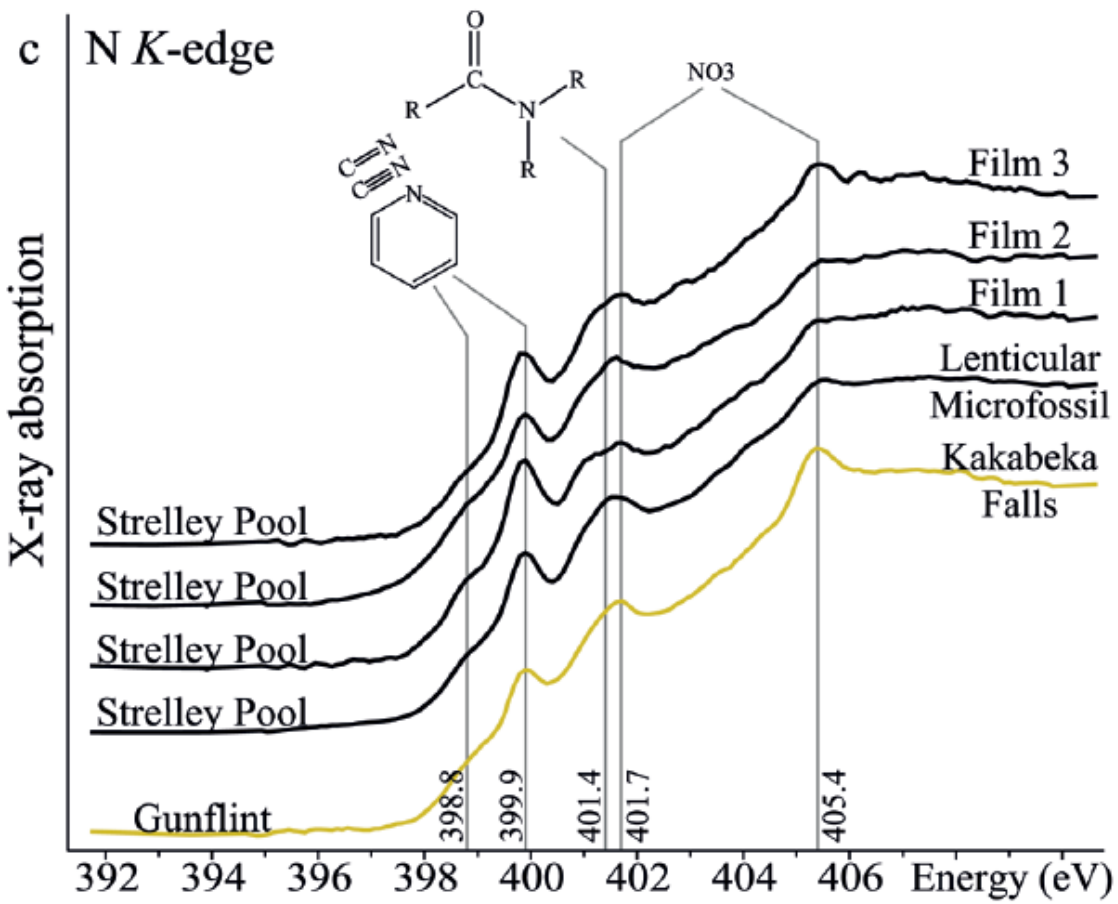
Alléon et al. 2018



X-ray absorption spectroscopy (XANES)

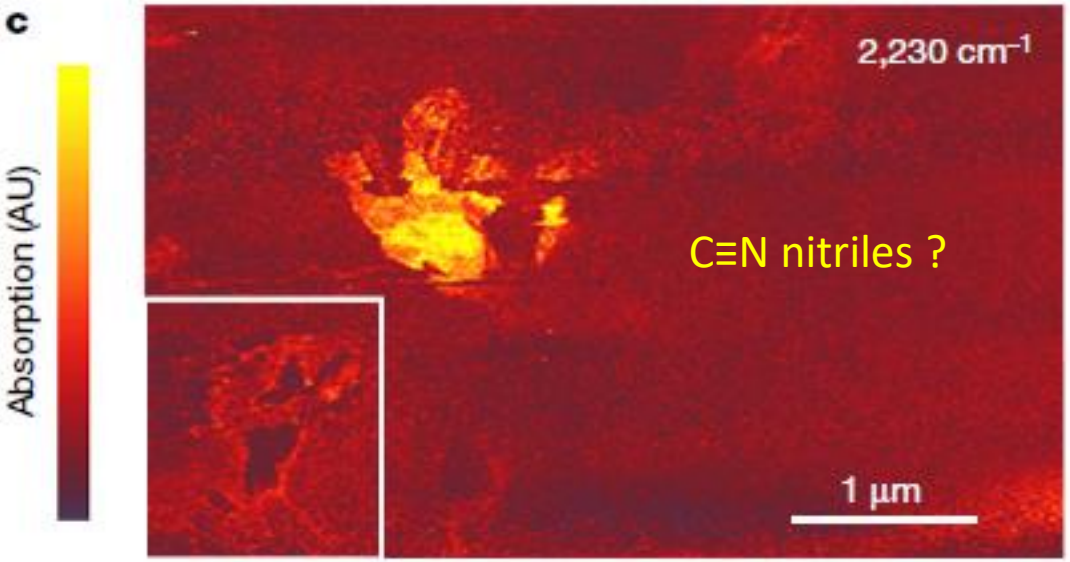
on carbonaceous structures in fresh fractures





Eoarchean graphite

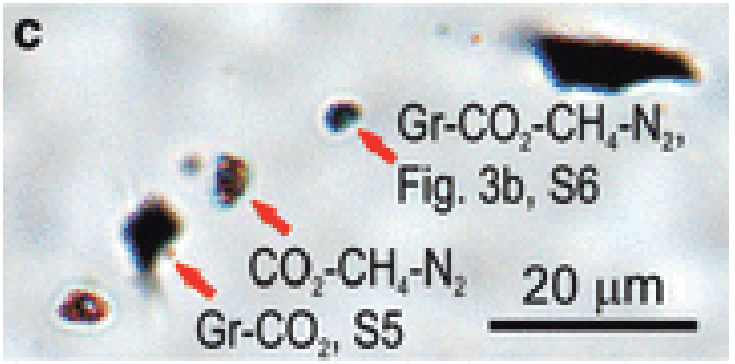
Isua graphite >3.7 Ga



Hassenkam et al. 2017

AFM-IR
C≡N nitriles ?
+C=C and C=O

Akilia ~3.83 Ga



Lepland et al. 2011

Graphite in fluid inclusion trails with CH_4+CO_2

Fluid-deposited during metamorphism

➔ Biogenicity?
➔ Age?

$\delta^{13}C$ values <-20 ‰ in Eoarchean graphite ➔ biogenic?

Tashiro et al. 2017
Komiya et al. 2017