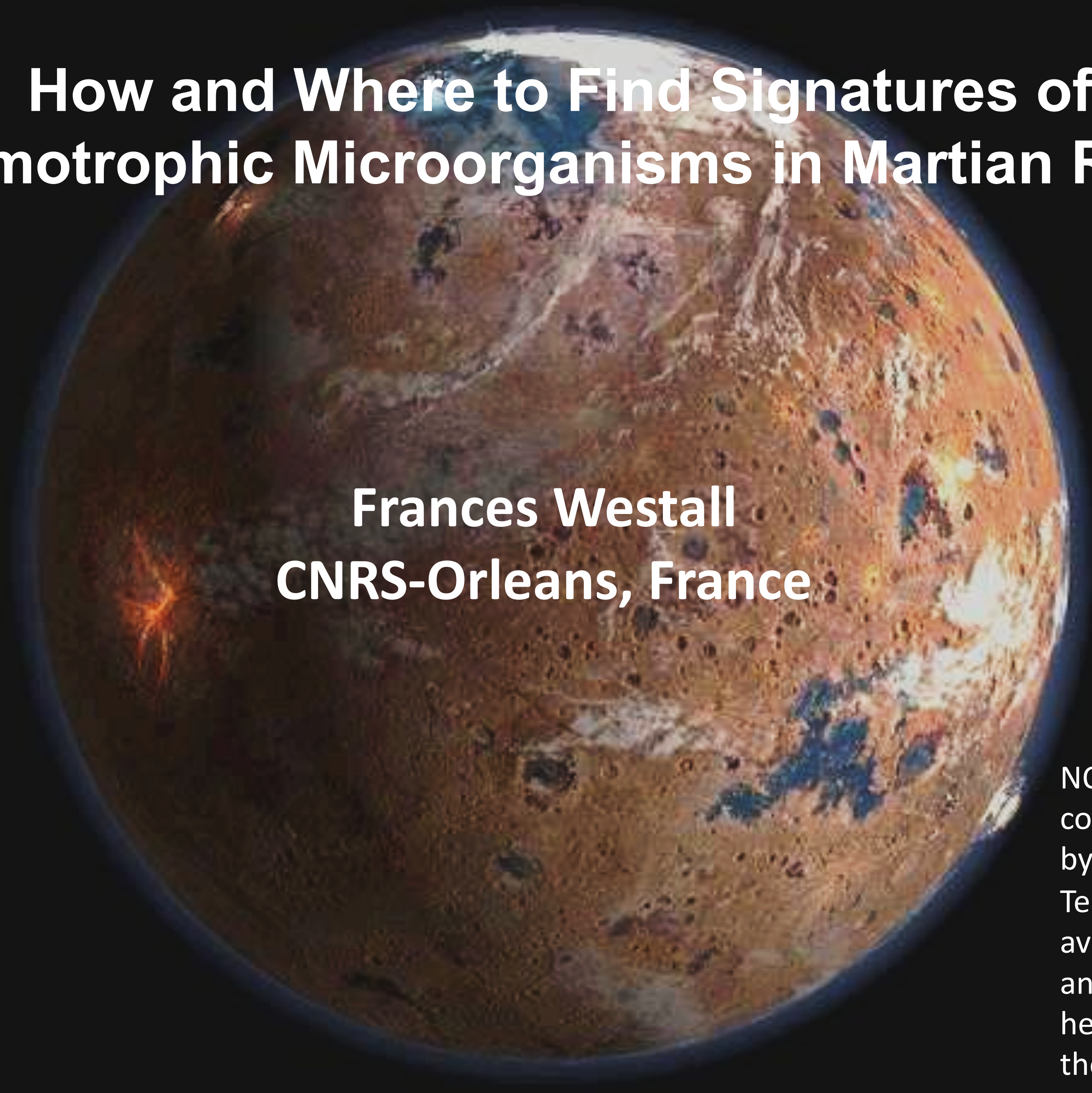
How and Where to Find Signatures of Chemotrophic Microorganisms in Martian Rocks



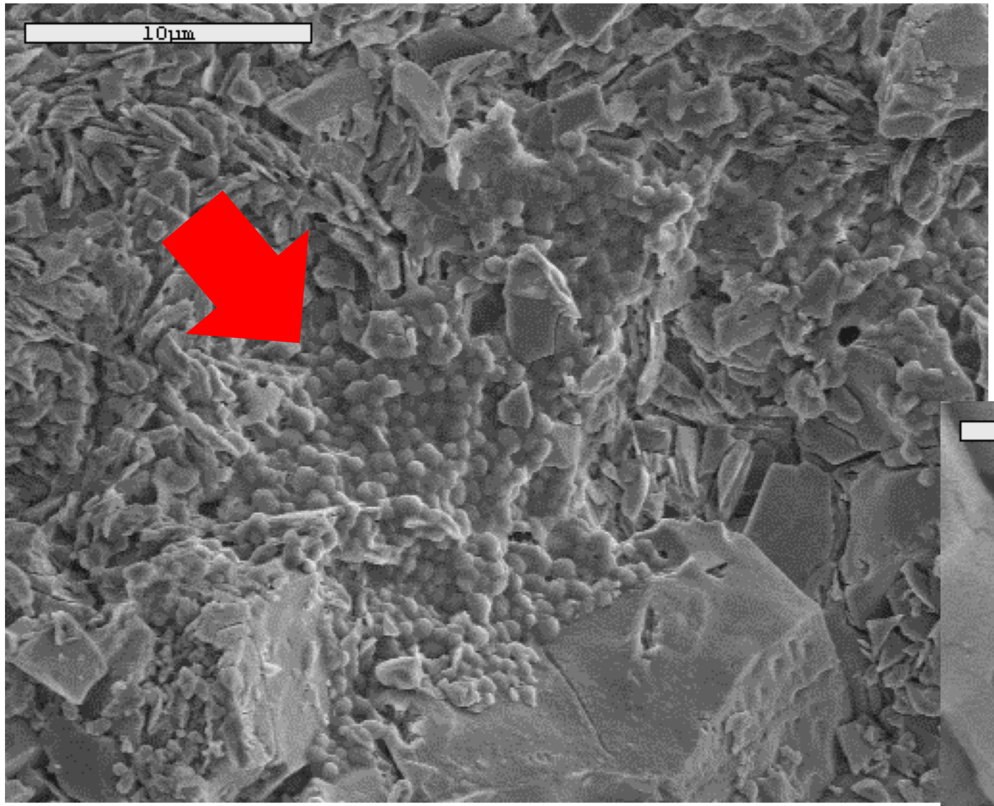
Frances Westall
CNRS-Orleans, France

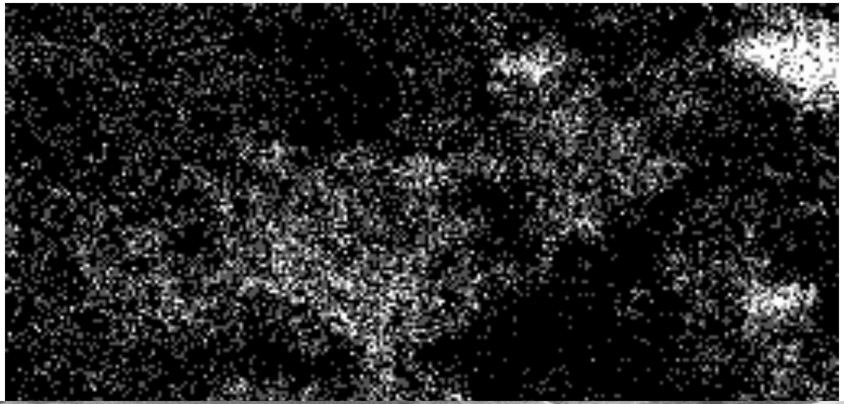
KEY PREMISES

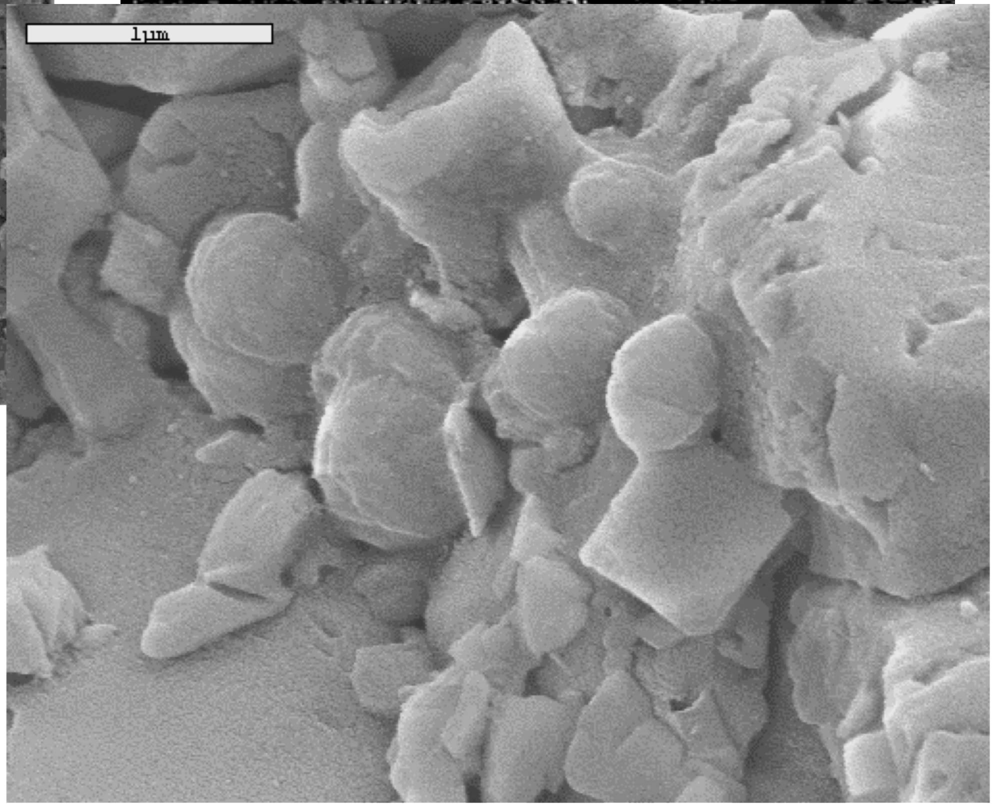
1. Chemotrophs are the most likely microbes to have existed (exist) on Mars because of its history of punctuated habitability (but cannot exclude phototrophs)
2. Terrestrial life inhabits all known environments below ~120°C
3. Early chemotrophic terrestrial life (good analogue for an anaerobic planet) was polyextremophile
4. Early chemotrophic terrestrial life was abundant in nutrient-rich hydrothermal environments
5. Early chemotrophic terrestrial life lived also in more nutrient-poor environments
6. Good preservation of biosignatures (morphological, organic, other) depends on rapid mineral encapsulation
7. Long-term preservation of biosignatures depends on degree of chemical changes (diagenesis, burial metamorphism, oxidation, radiation), physical changes (destruction by mass wasting, erosion, impacts etc.)

Biosignature preservation

Biosignatures:
Morphological







Note scale: SEM images
Chemolithotrophs, Pilbara 3.45 Ga

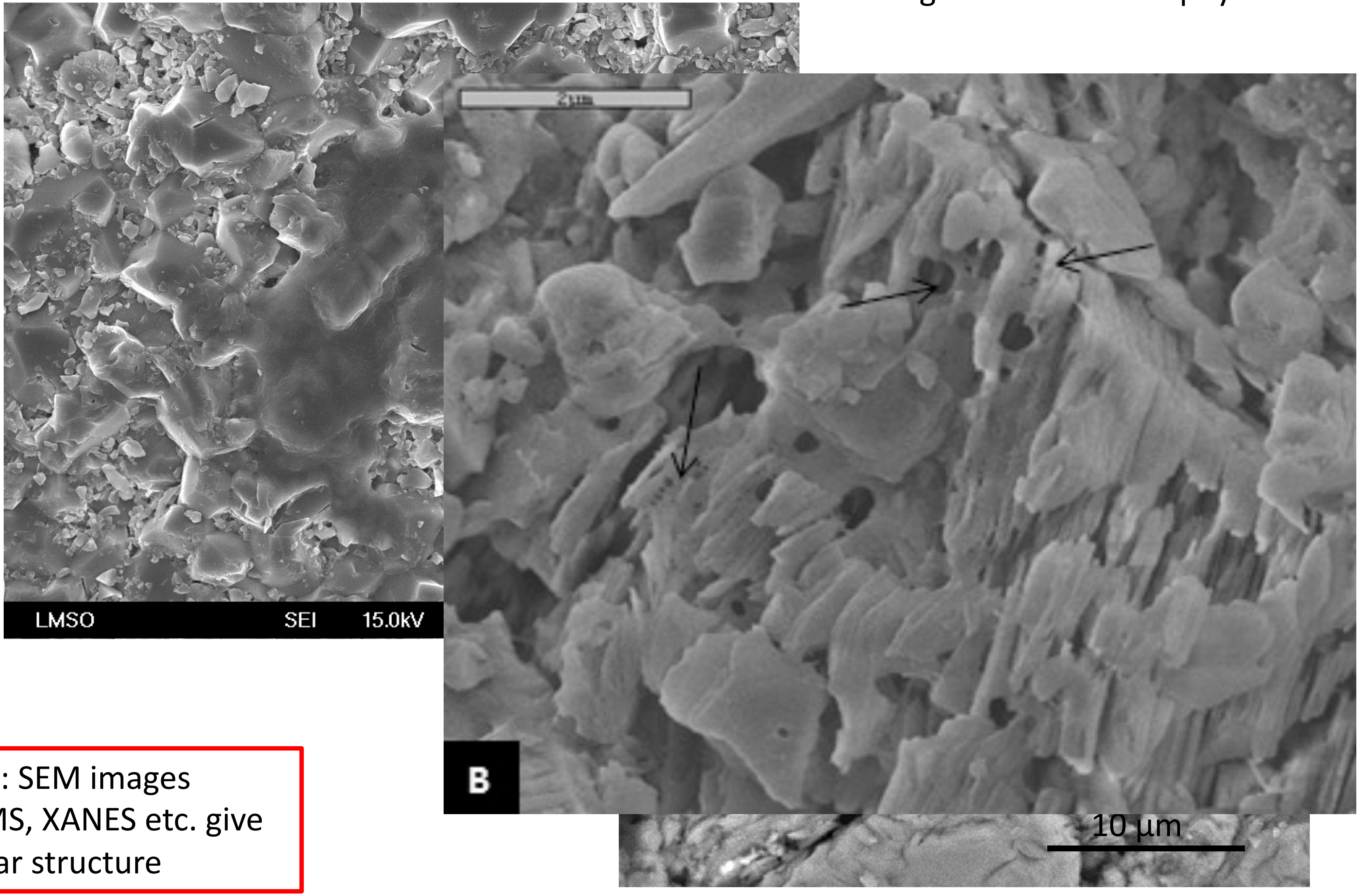
Westall et al., 2006, 2011, 2015

Biosignature preservation

Organic filaments in phyllosilicates

Biosignatures:
Organic

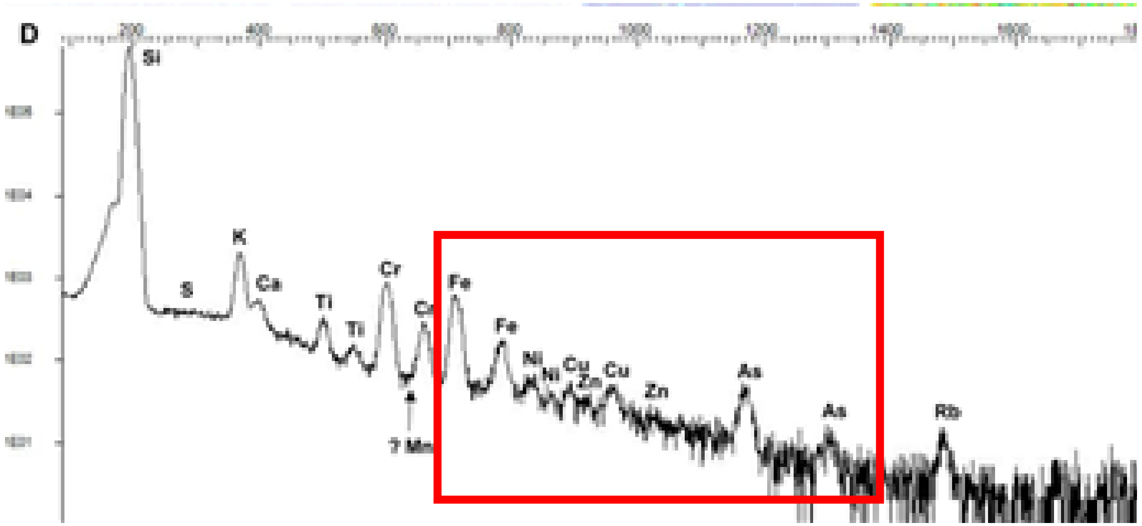
In situ



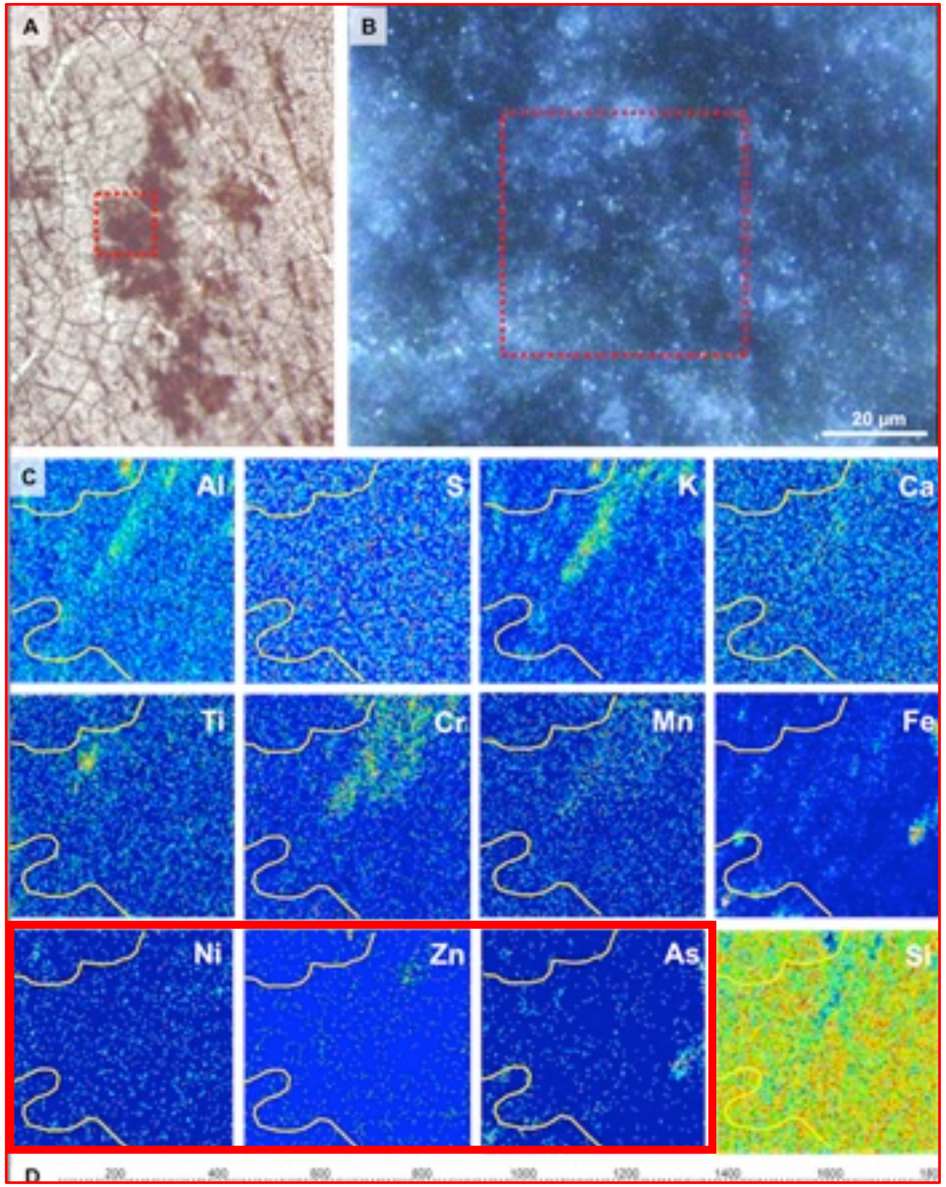
Note scale: SEM images
BUT MS/ToFSIMS, XANES etc. give
molecular structure

Biosignature preservation

Biosignatures:
Other:
Elemental concentrations (transition metals) related to metallome (*s.l.*)



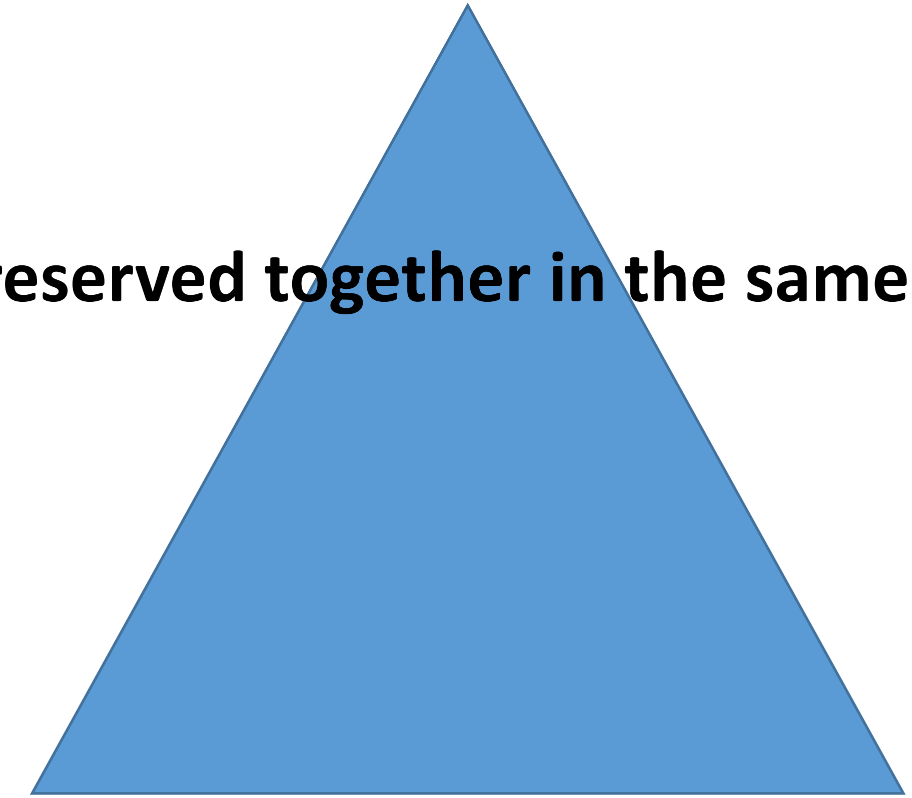
Note scale: µPIXE
Chemotrophs, Barberton 3.33 Ga



Hickman-Lewis et al., in review

Sources of carbon

Abiotic/prebiotic
(extraterrestrial, endogenous)



These can all be preserved together in the same sedimentary facies

Detrital
(abiotic, prebiotic, biogenic)

Biogenic

Biosignature preservation potential

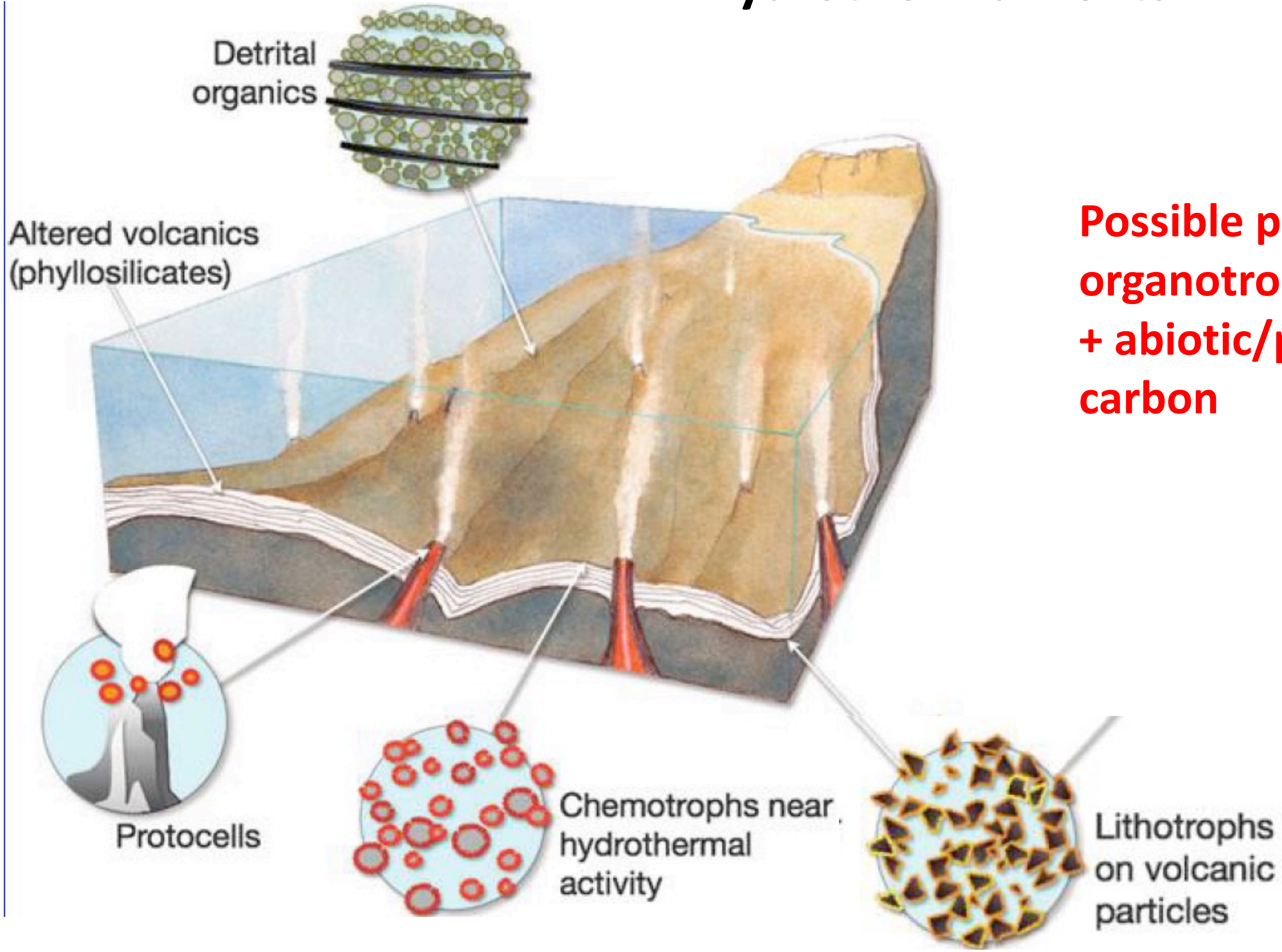
Biosignatures:
Morphological
Organic
Other

Long term effects:
Burial metamorphism
Oxidation
Radiation
Physical

Sedimentary facies		**Mineral matrix**	**Diagenesis**			
			Early	Biosignature	**Late**	Biosignature
Coarse volcanics		Sulphate	☺	Morph, org	☹	
		Carbonate	☺	Morph, org	☹	
		Clays	☺	Organics	☹	
		Silica	☺	Morph, org	☺ (acid)	Morph, org
Fine volcanics		Sulphate	☺	Morph, org	☹	
		Carbonate	☺	Morph, org	☹	
		Clays	☺	Organics	☹	
		Silica	☺	Morph, org	☺ (acid)	Morph, org
Chemical sediments	Sulphate		☺	Morph, org	☹	
	Silica		☺	Morph, org	☺ (acid)	Morph, org

Note: silica can be hydrothermal, diagenetic, evaporitic

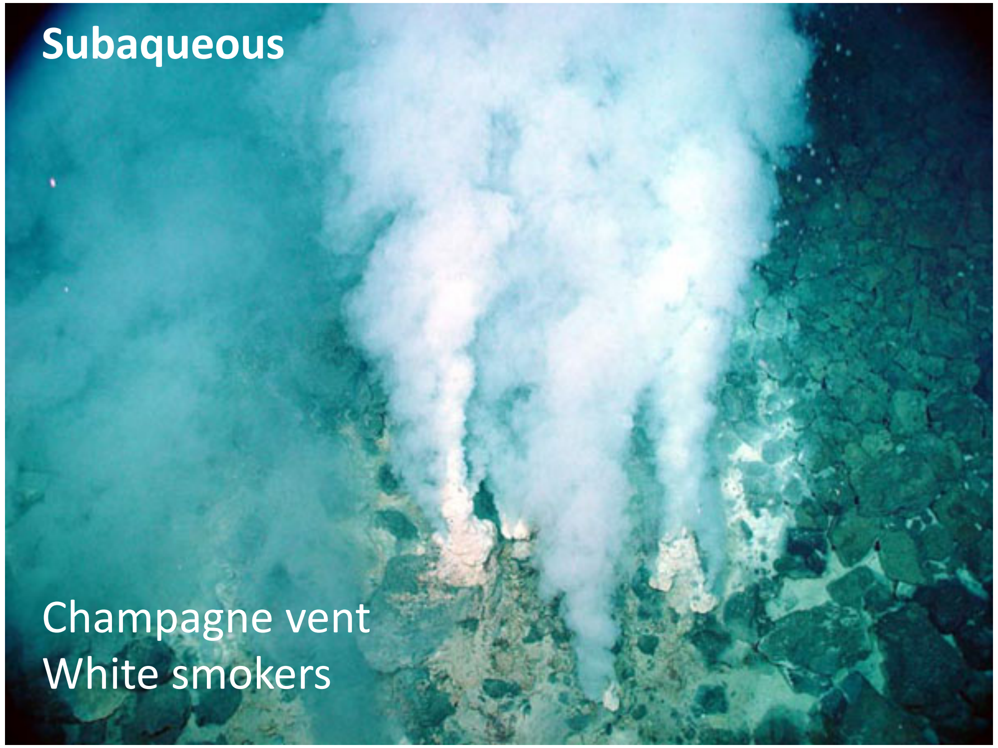
Habitats and microorganisms 1
Hydrothermal vents → nutrient-rich environments



Possible protocells, chemolithotrophs, organotrophs
+ abiotic/prebiotic (ET, endog.), detrital carbon

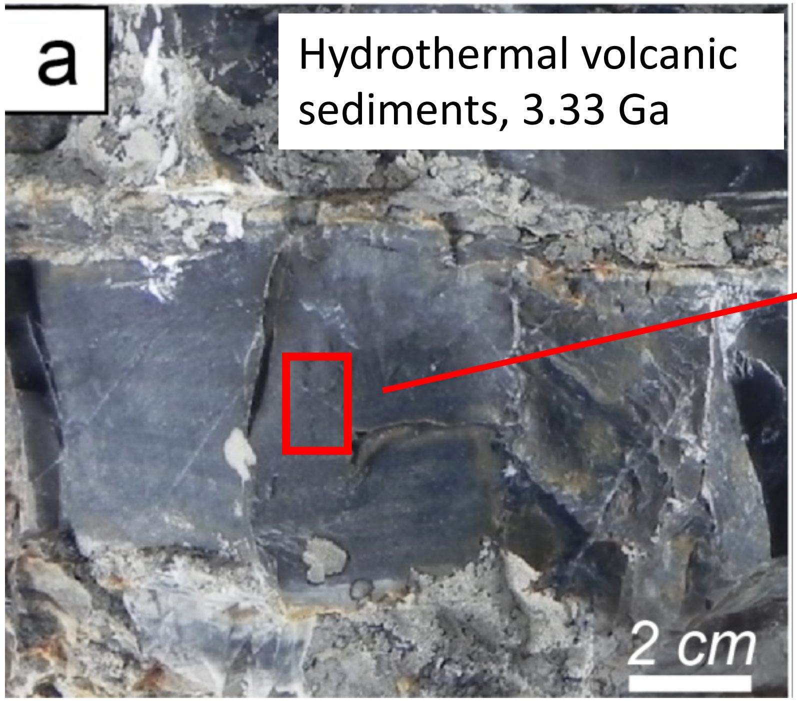
Westall et al., 2015, Astrob
Vago, Westall et al., 2017, Astrobiology

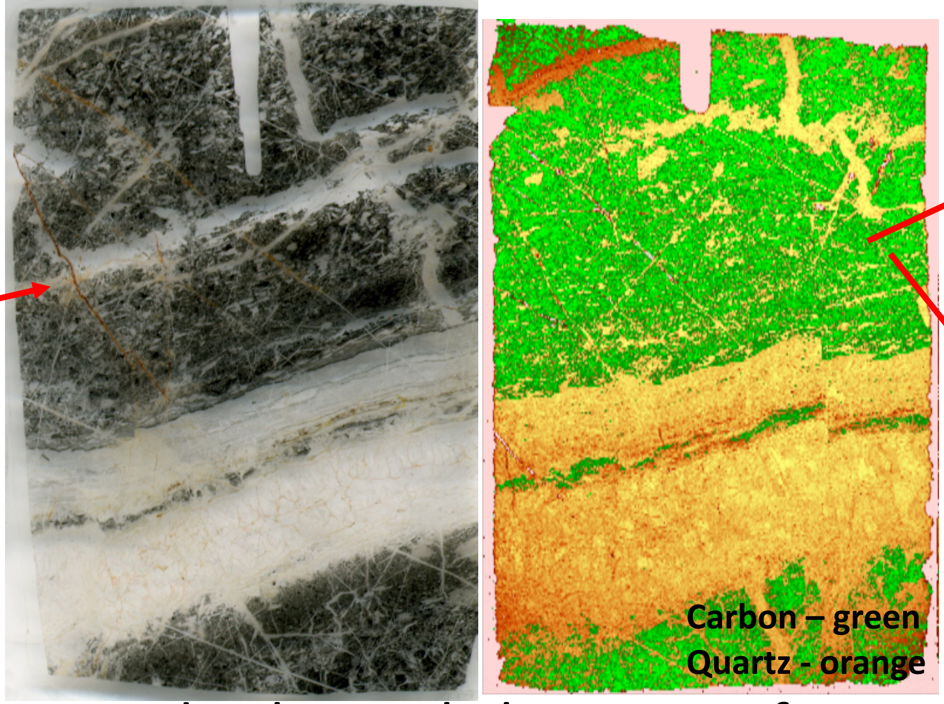
Nutrient-rich hydrothermal environments

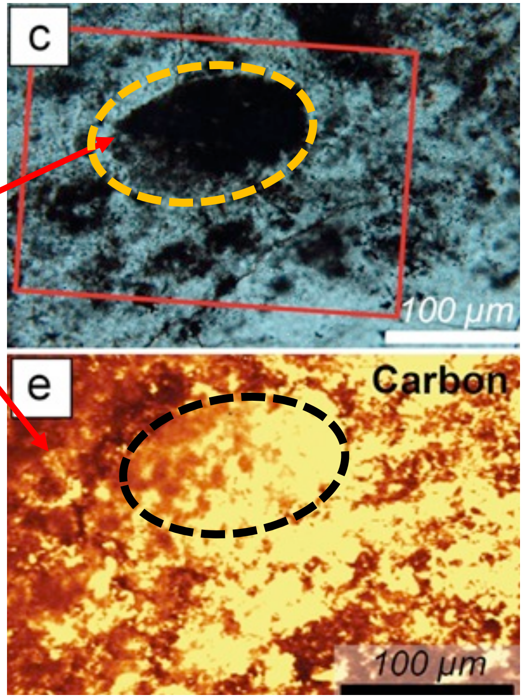


Nutrient-rich hydrothermal environments

Early anaerobic Earth







Black sediments (carbon-rich), faint laminations (biofilms)

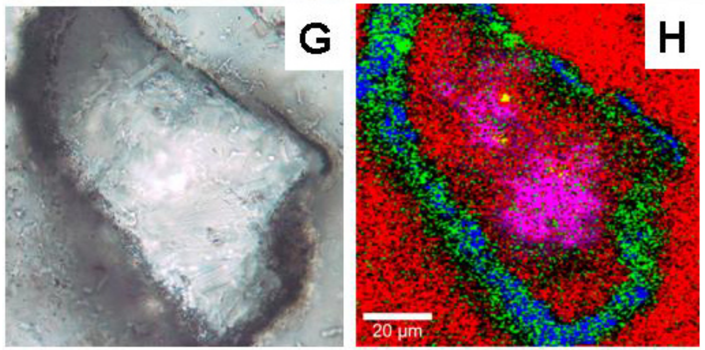
Hydrothermal alteration of volcanics

→ phyllosilicates+ silica

Clotted texture

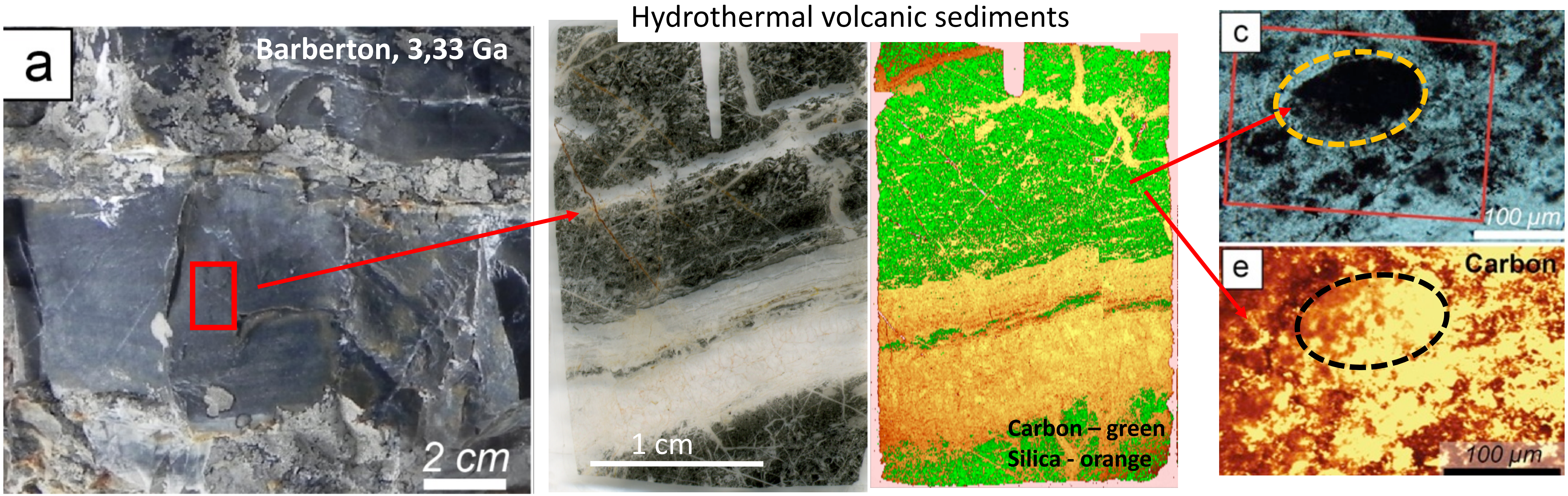
→ all volcanic particles totally colonised by colonies of chemotrophs

Pink: muscovite
Green: carbon
Blue: anatase
Red: quartz



Westall et al., 2015, Astrobiology

Nutrient-rich hydrothermal environments



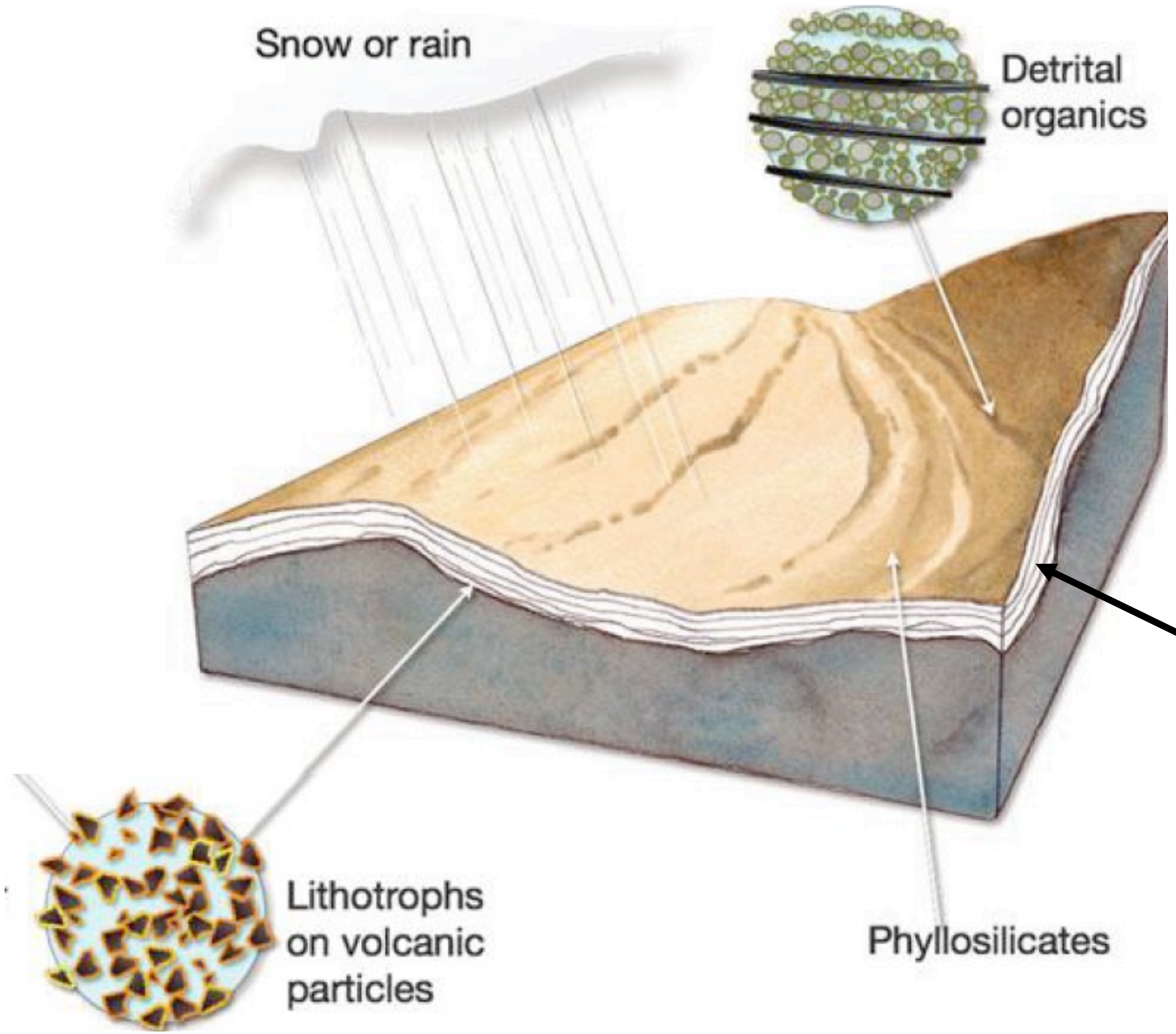
PANCAM
SUPERCAM

WATSON

SHERLOC
PIXL

SHERLOC

Habitats and microorganisms 2
Oligotrophic nutrient-poor environments

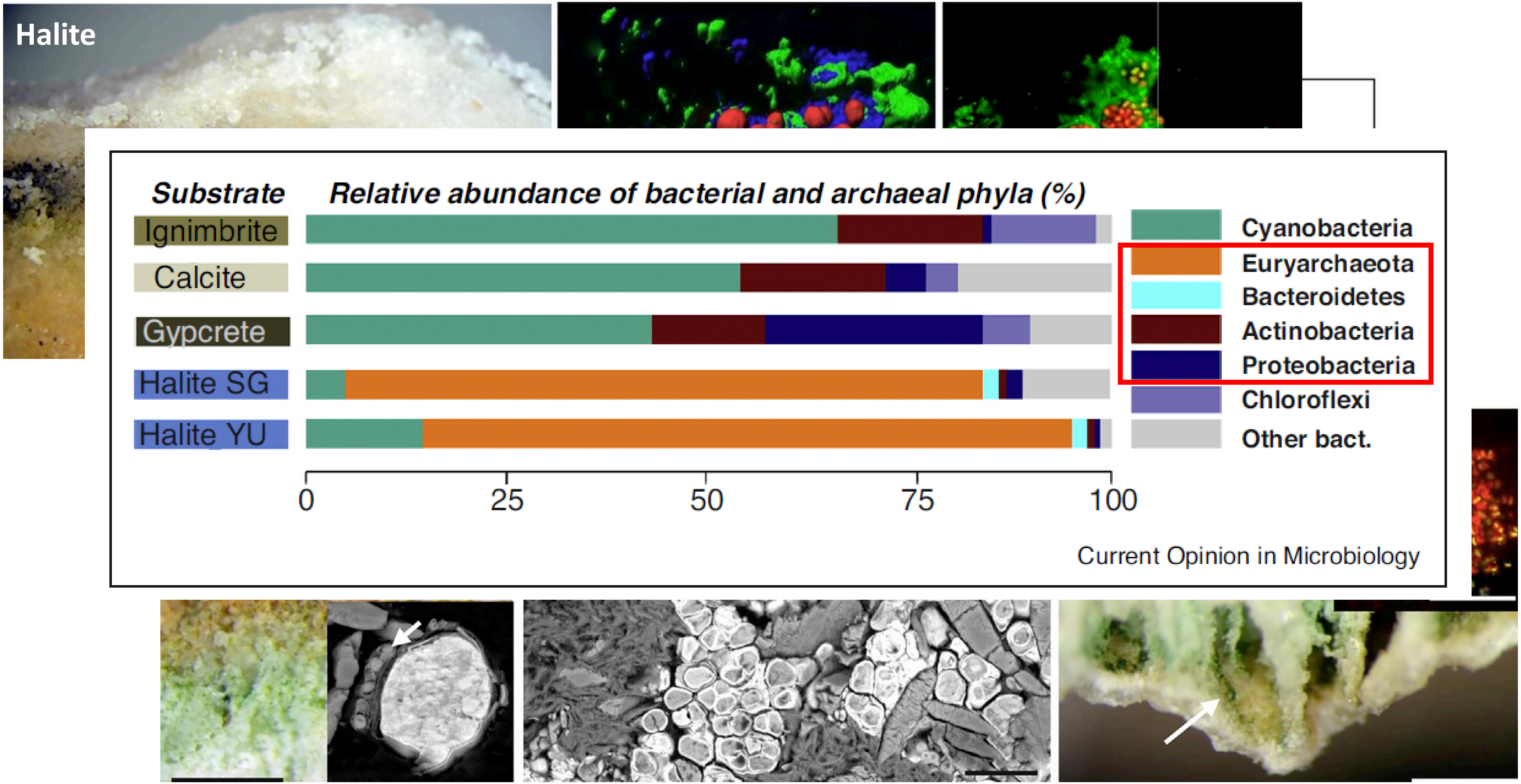


Chemolithotrophs
+ abiotic/prebtioic (ET, endog.), detrital carbon

Crustal environments

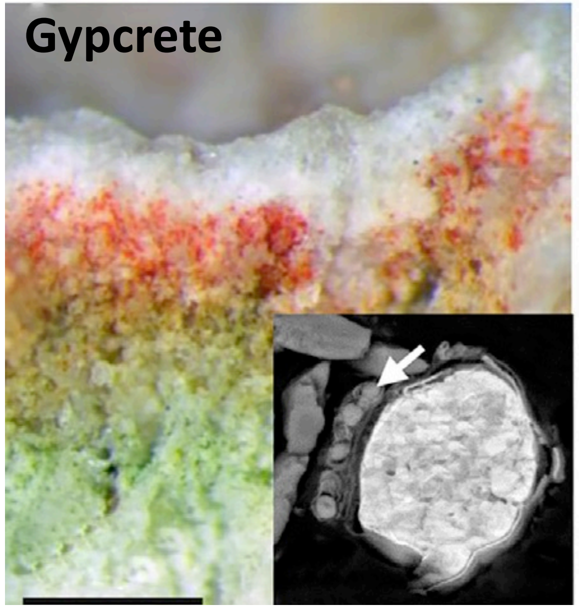
Vago, Westall et al., 2017, Astrobiology

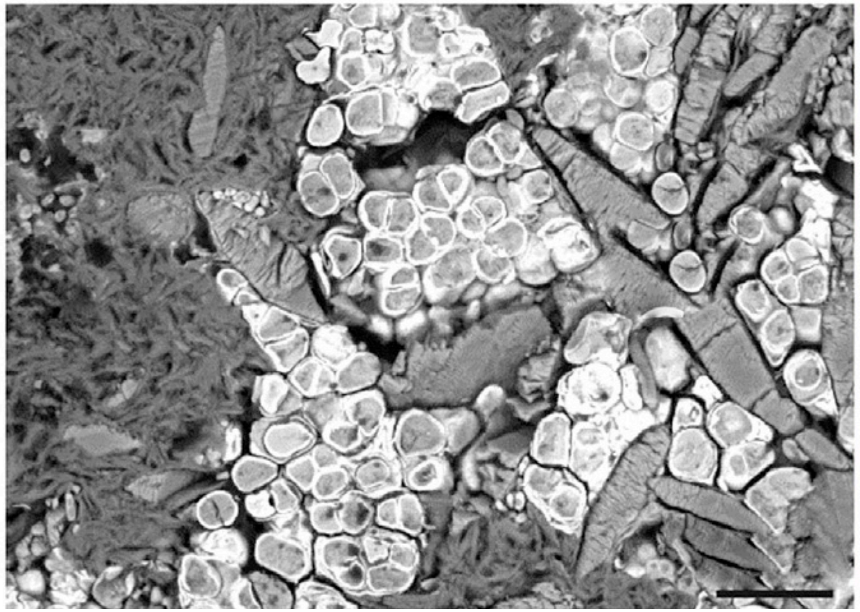
Oligotrophic nutrient-poor environments:

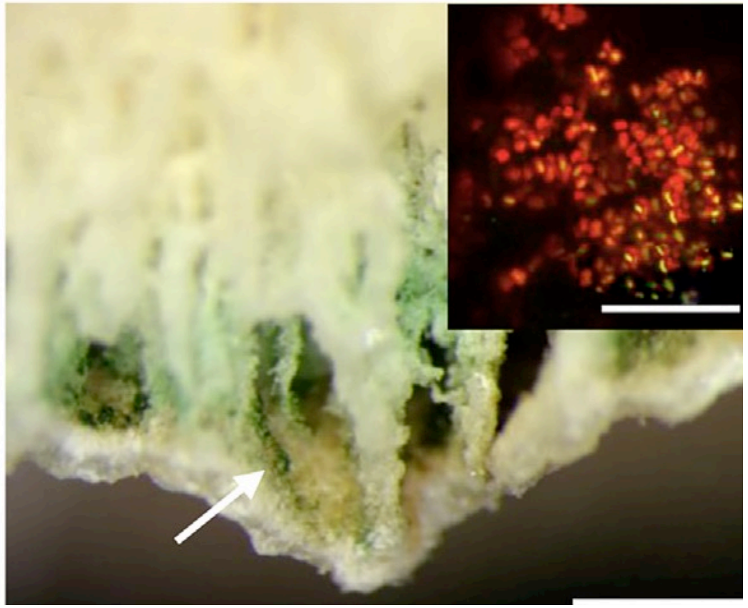


Wierzchos et al., 2018 Current opinion in microbiology

Oligotrophic nutrient-poor environments





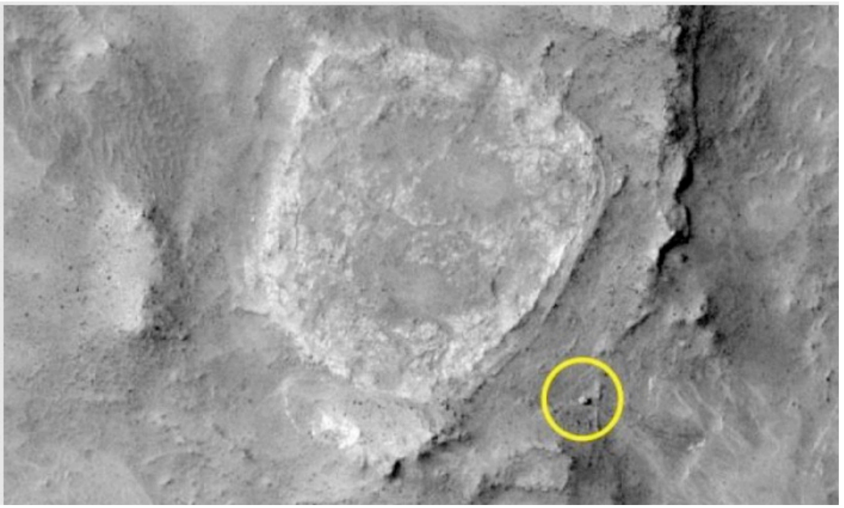


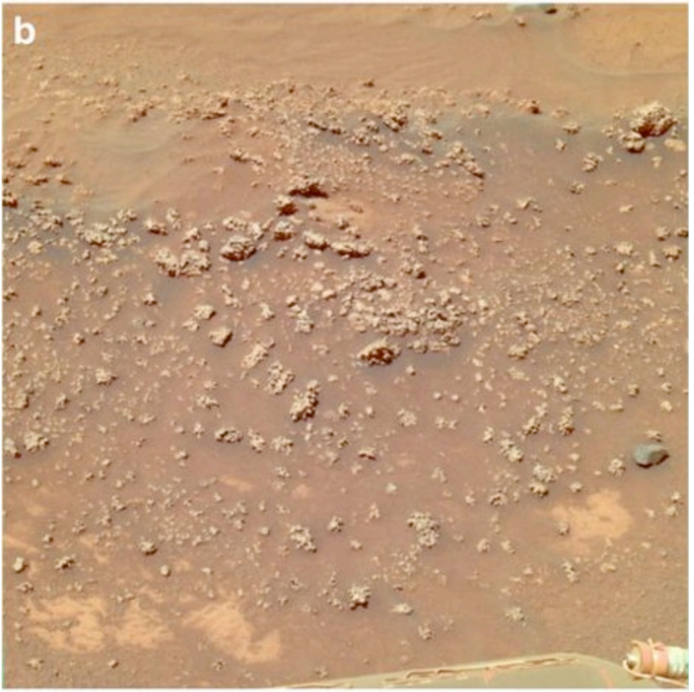
PANCAM
SUPERCAM

WATSON

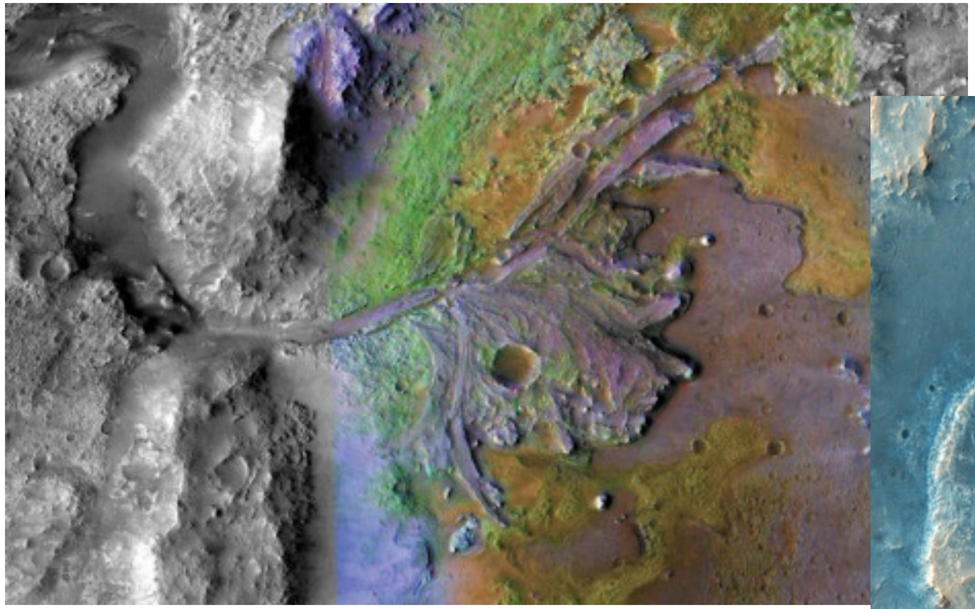
SHERLOC
PIXL

Columbia Hills and Home Plate

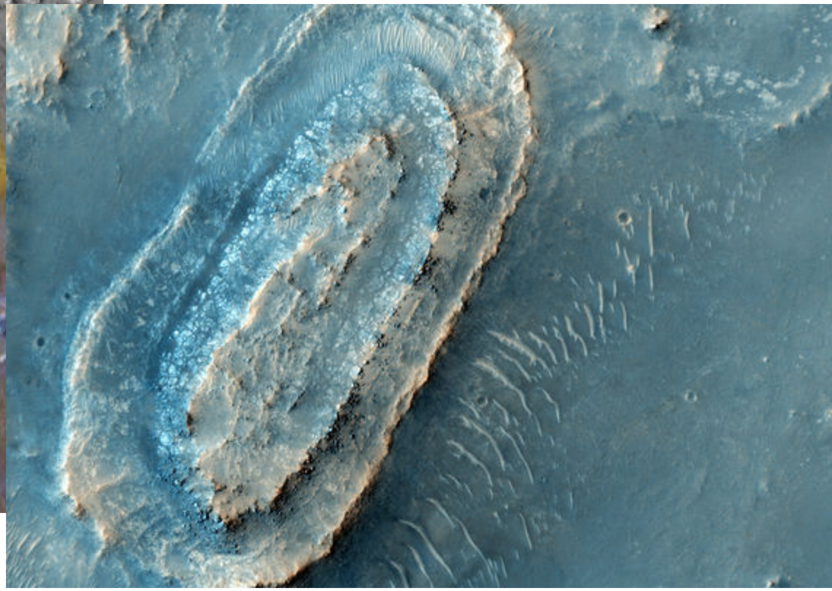




Jezero



NE. Syrtis



Lake sediments, deltas, hydrothermal (?)

Alteration mineralogy: clays, salts, silica, other

Effects of later diagenesis (ground water, pedogenesis, rain, snow)

→ Look for primary, unaltered fabrics

→ Look for late stage chemical precipitates that have not been altered

CONCLUSIONS

1. Highest chemotrophic biomass is close to hydrothermal activity
2. Polyextremophilic chemotrophs have a wide environmental distribution
3. Best long-term preservation is in a silica matrix
4. Long-term preservation in other mineral matrices possible, provided there is no subsequent flushing by fluids having corrosive pH/Eh properties
5. Likelihood of having a mixed carbon signature is high (abiotic/prebtioitc+detrital+*in situ* biogenic)
6. Chemotrophic biosignatures could be everywhere – if it can get there - and nowhere

→ Assume that traces of life are present at any landing site, especially if there is carbon in the sediments

→ Detailed analyses to prove biogenicity need sample return

Biosignature preservation

Biosignatures:
Other:
e.g. corrosion tunnels