Ancient habitability in Early Archaean (3.5-3.3 Ga) volcanic and sedimentary rocks:

Relevance for habitability in Noachian/Hesperian materials on Mars

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Habitability

Liquid water
Carbon
Energy
Nutrients

} Ingredients of life

→Long term sustainability of life requires tectonic recycling of crust (reservoirs of carbon, nutrients etc)

Habitability

<u>SOURCES</u> (for terrestrial planets)

- **Liquid water – LHB materials, micrometeorites, comets**
- **Carbon - LHB materials, micrometeorites, comets**
- **Energy - hydrothermal, chemical, light**
- **Nutrients - rocks**

→The terrestrial planets were habitable as soon as there were stable bodies of liquid water at temperatures =/< 80°C

HABITABILITY: Microbial scales

Habitability scales	Time	Space
Origin of life	10^5-10^6 y?	10^1-10^3 km
Established life	Day-weeks-years	10^2-10^3 µm
Survival	10^{-1}–10^6 y?	10^2-10^3 µm

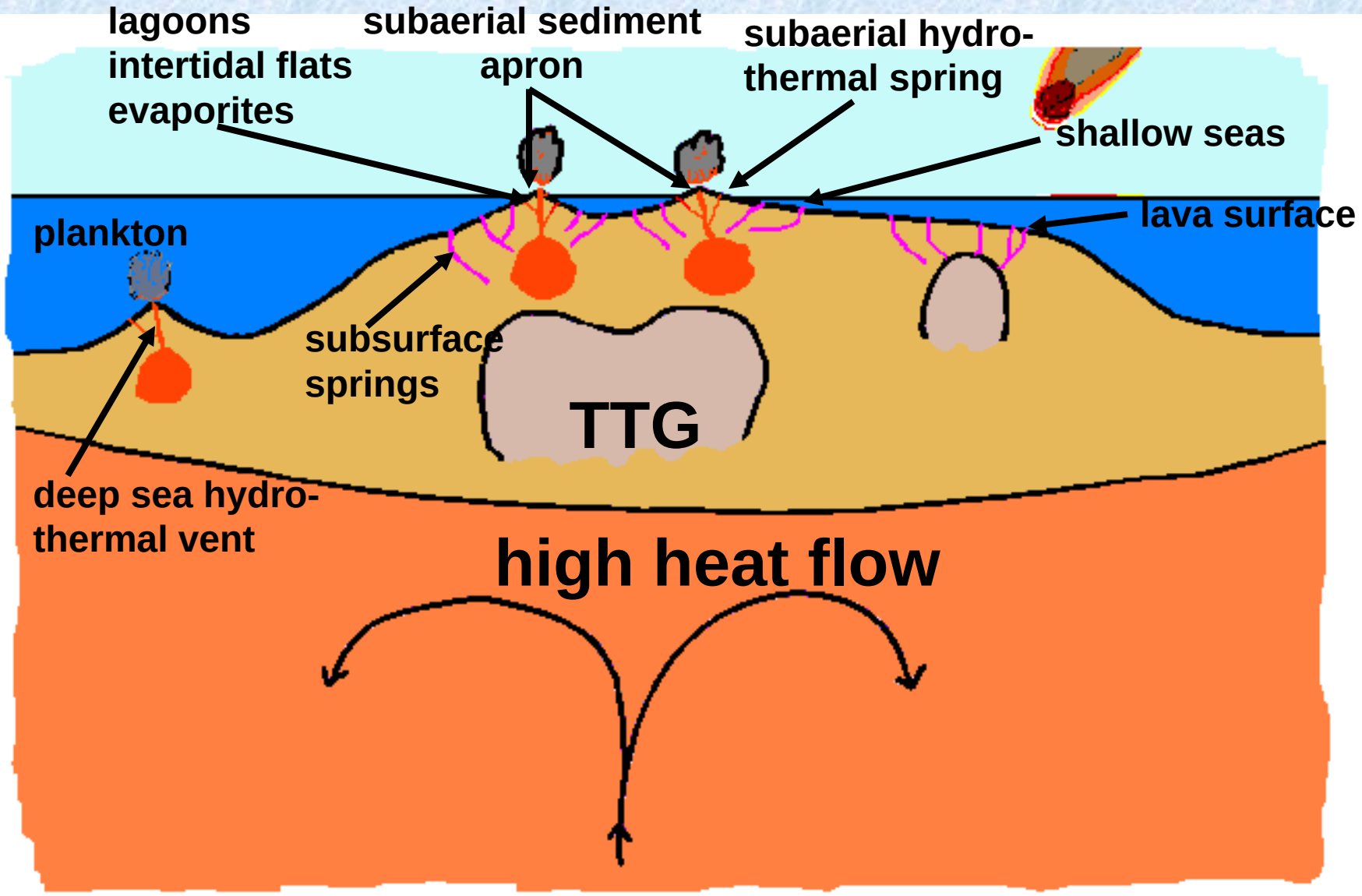
→The habitable zone does not need to cover the whole planet

→Long term sustainability of life requires tectonic recycling of crust (reservoirs of carbon, nutrients etc)

Early Earth – an ocean planet

Land
– early continents mostly submerged

Potential Archaean microbial habitats



Early Mars – a land-locked planet

Habitability scales	Time	Space
Origin of life	10^5-10^6 y?	10^1-10^3 km
Extant life	Day-weeks	10^2-10^3 µm
Survival	10^{-1}–10^6 y?	10^2-10^3 µm

→ **Early Mars was habitable**

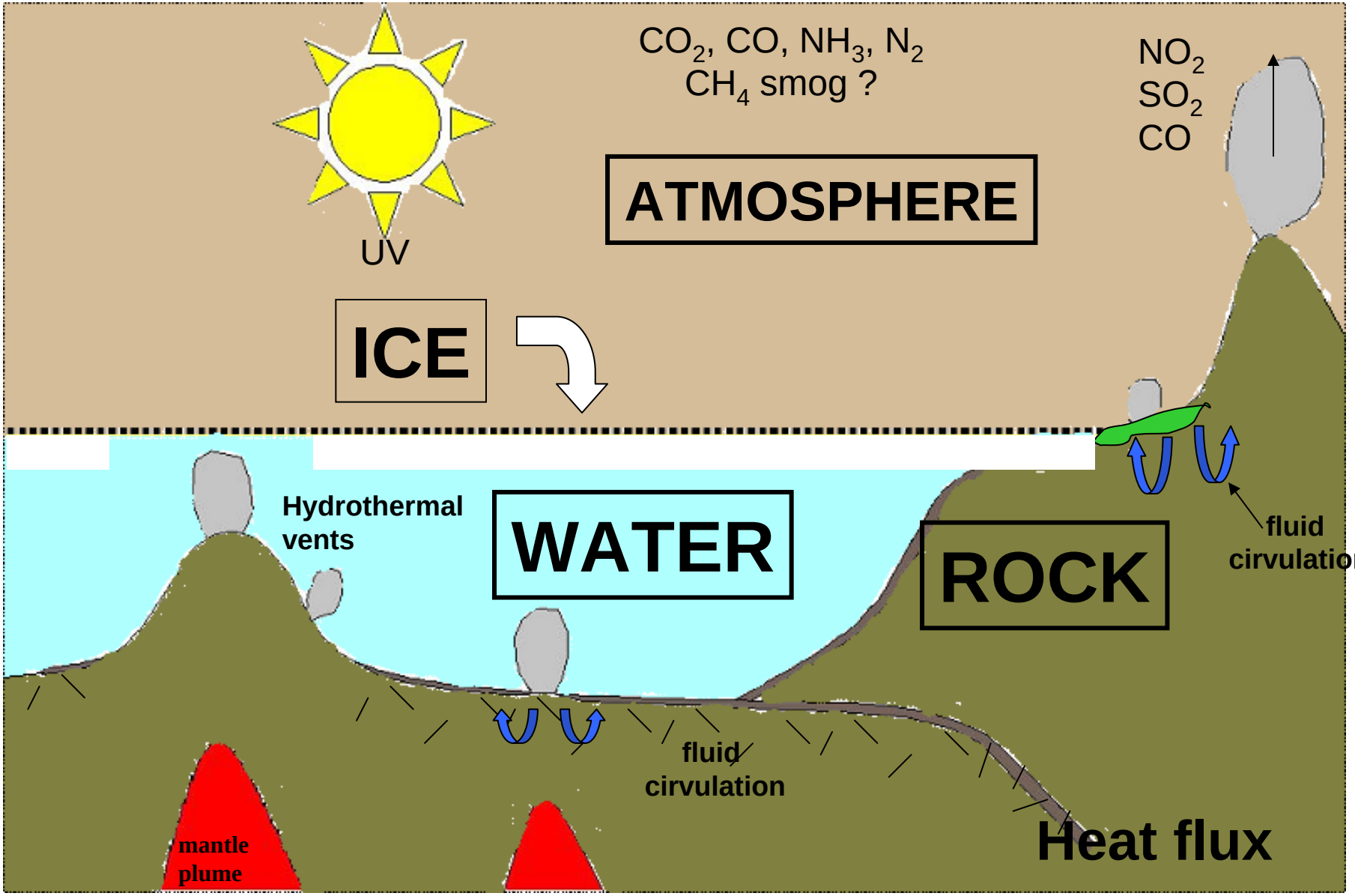
Environmental conditions on the early Earth/Mars

	Earth 3.5 Ga	Mars 4.0 Ga
Ocean T°C	~55 (> 100)	~0- >[illegible]
Atmosphere	CO_2, greenhouse gases, < 0.2% PAL [illegible]	[illegible]enhouse [illegible]s, < 0.2% PAL O_2
pH	Slightly acid[illegible]	Slightly acidic - neutral
Radiation *Cockell, Raven, 2004	54 W[illegible])*	54 W/m2 (1000)*
Hydrothermalis[illegible]	[illegible]mely active	Extremely active
Volcanism	Extremely active	Extremely active
Impacts	Frequent	Frequent

Extreme but habitable

Habitable environments on the early Earth (and Mars)

Habitats on the early Earth/Mars



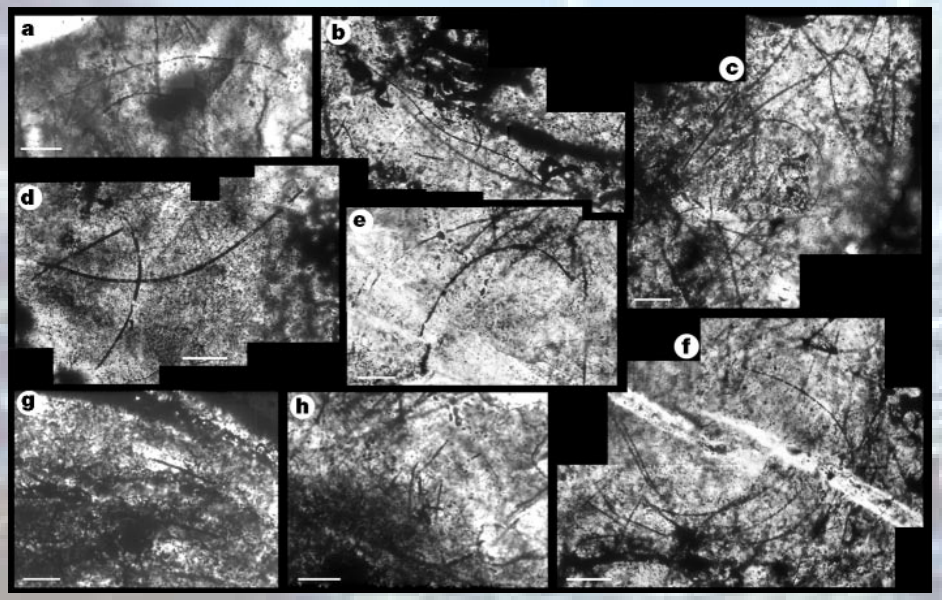
Habitable environments on the early Earth

Habitats	Energy (E) and Carbon (C) sources	Organism types
Hydrothermal vents/springs (deep, shallow)	C/E from inorganic/organic sources,	Thermo-mesophilic chemolithotrophs/ organotrophs
Deep sea floor: sediments; crustal cracks; Lava surfaces	C/E from inorganic/organic sources	Thermo-mesophilic chemolithotrophs/ organotrophs
Littoral environments (photic zone); sediments; lava surfaces,	C/E from inorganic/organic sources, E from sunlight	Thermo-mesophilic chemolithotrophs/ organotrophs/ phototrophs
Water column??	C/E from organic sources, E from sunlight	Phototrophs/ organotrophs

Habitable environments on the early Earth

Habitats	Energy (E) and Carbon (C) sources	Organism types
Hydrothermal vents/springs (deep, shallow)	C/E from inorganic/organic sources,	Thermo-mesophilic chemolithotrophs/ organotrophs

Deep sea black smoker

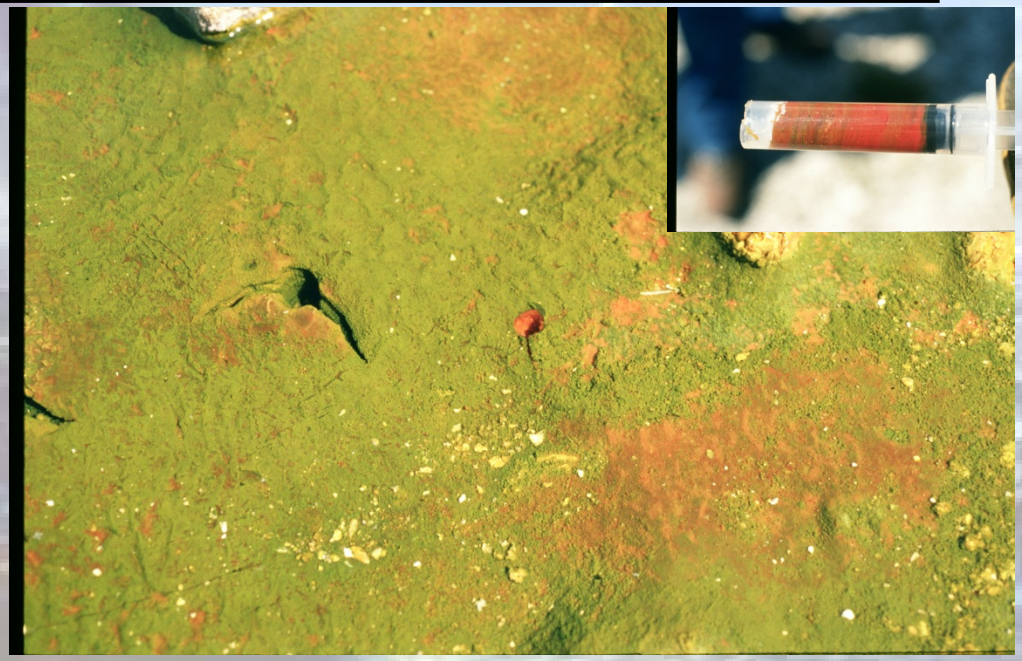


Microbial filaments (?) in a VMS deposit, N. Pole Australia (3.2 ga)
Rasmussen, Nature 2000, 405, 676

Habitable environments on the early Earth

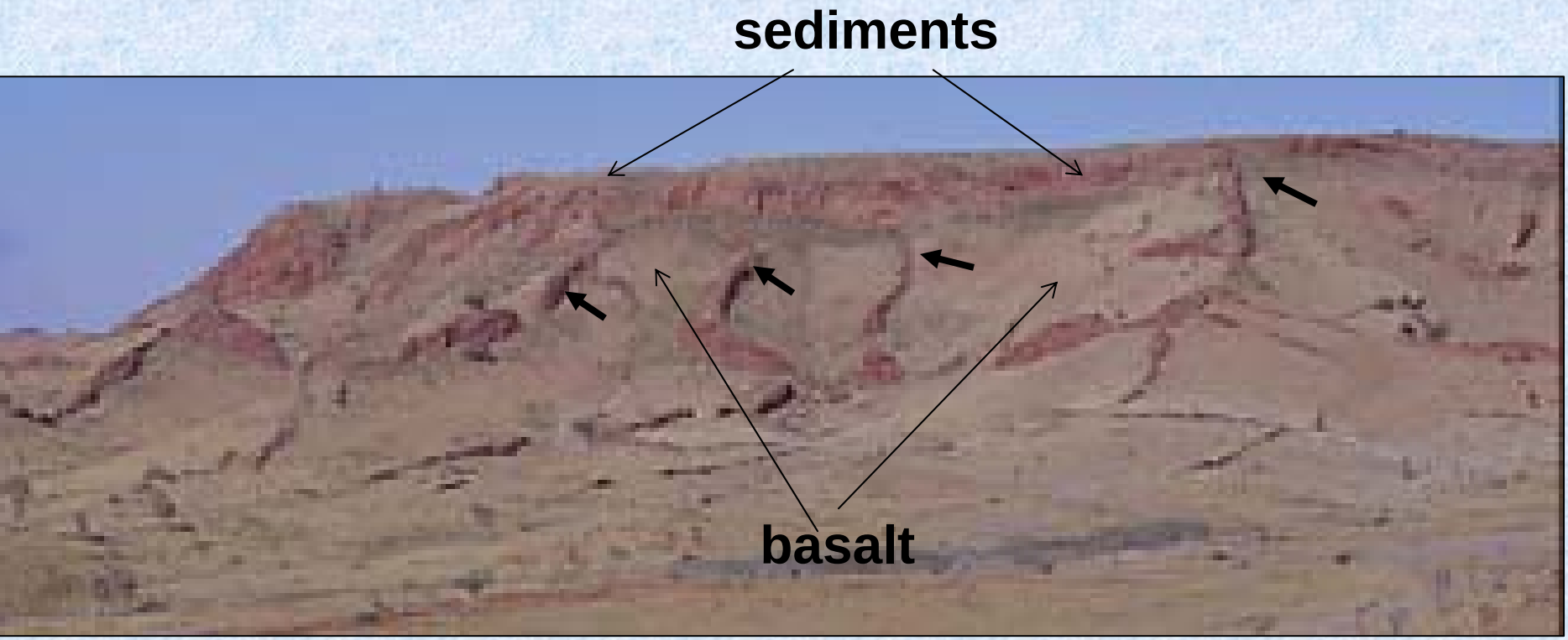
Habitats	Energy (E) and Carbon (C) sources	Organism types
Hydrothermal vents/springs (deep, shallow)	C/E from inorganic/organic sources, light	Thermo-mesophilic chemolithotrophs/ organotrophs phototrophs

Hot spring (Yellowstone)



Photosynthetic microbial mats

Hydrothermal chert veins



Nijman et al. 1998

Habitable environments on the early Earth

Habitats	Energy (E) and Carbon (C) sources	Organism types
Deep sea floor: sediments; **crustal cracks;** **Lava surfaces**	C/E from inorganic/organic sources	Thermo-mesophilic chemolithotrophs/ organotrophs

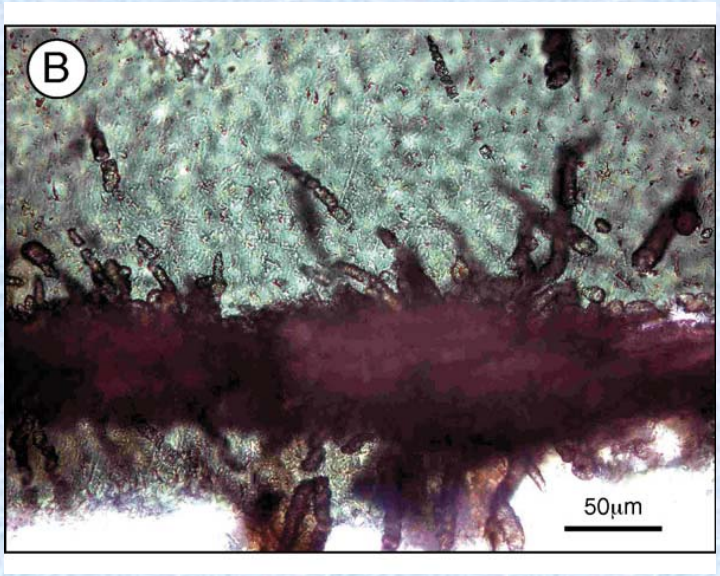
Submarine pillow basalts

Barberton, 3.4 Ga

Pillow basalts and microbial corrosion

Corrosion tunnels in the surfaces of volcanic pillow lavas

→ probably chemotrophs (obtain energy from redox reactions at the surface of minerals



Corrosion tunnels
Barberton
3.5 Ga

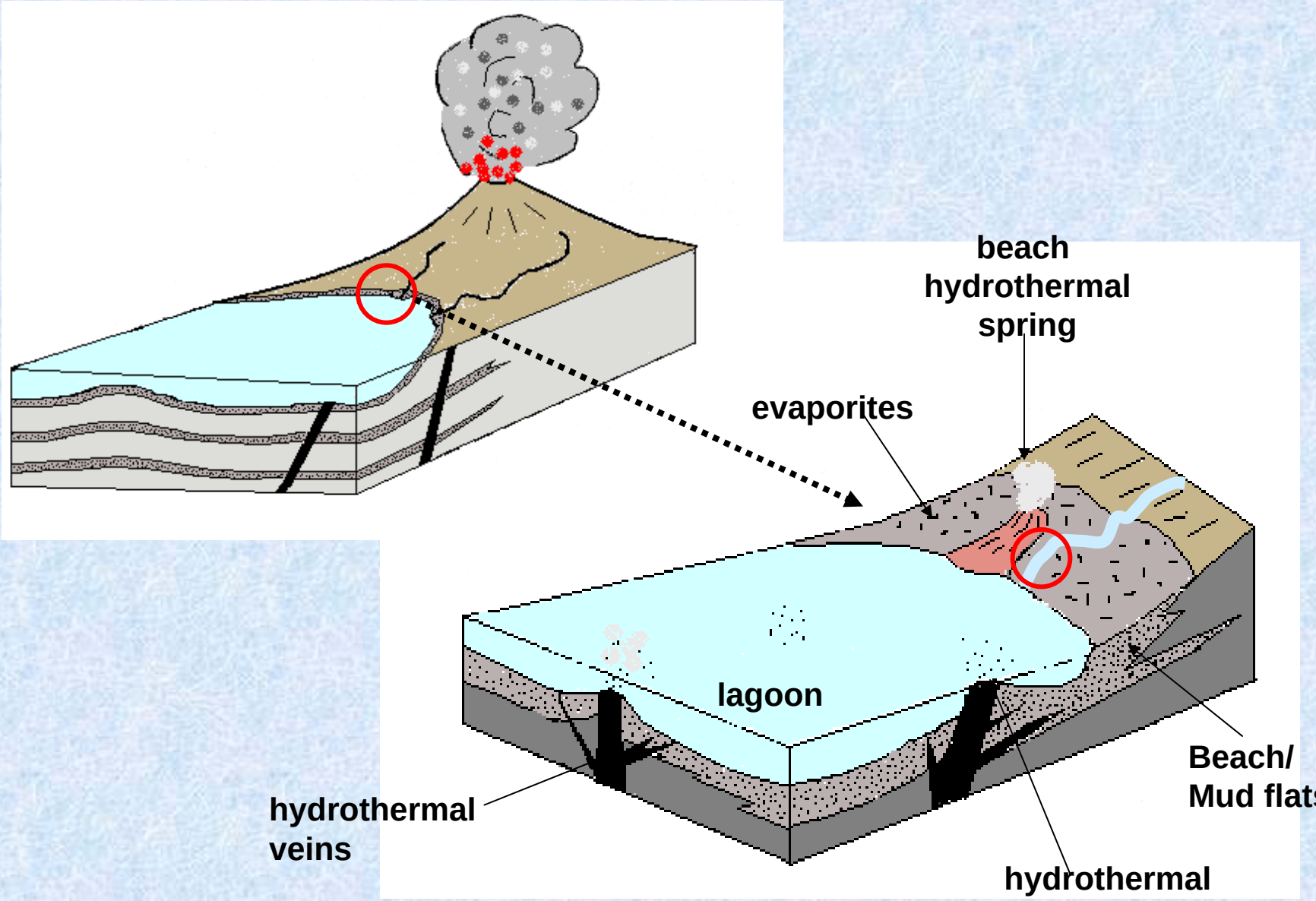
Modern

Furnes et al. 2007
Precambrian Res.,
158, 156

Habitable environments on the early Earth

Habitats	Energy (E) and Carbon (C) sources	Organism types
Littoral environments (photic zone); sediments; lava surfaces,	C/E from inorganic/organic sources, E from sunlight	Thermo-mesophilic chemolithotrophs/ organotrophs/ phototrophs

The littoral environment on early Earth and early Mars



Modern analogue: Black sandy/muddy tidal flats on Iceland beach

Example – mudflat volcanic sediments
Pilbara, 3.446 Ga

Westall et al., 2006; de Vries et al., 2008

Mudflat volcanic sediments Pilbara, 3.446 Ga

suspension deposits

pumice

stabilised sediment surface

rippled volcanic sediments

rippled volcanic sediments

up

Mudflat volcanic sediments Pilbara, 3.446 Ga

up

Transgression ↔ regression

Exposure

lower → higher
water energy

Mudflat volcanic sediments Pilbara, 3.446 Ga

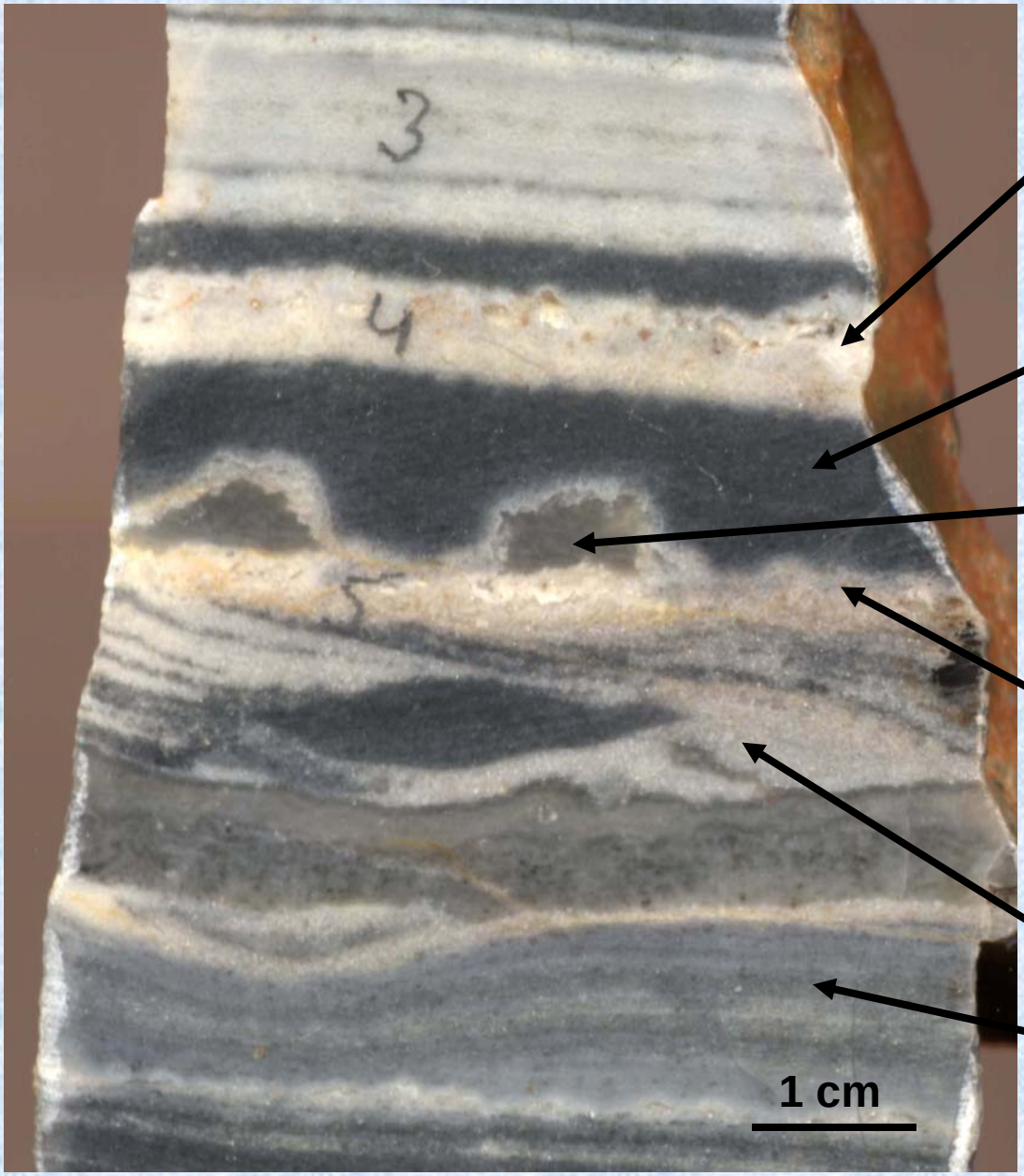
up

Rapid lithification
(seawater SiO_2 saturated, nearby hydrothermal silica vein*)

bedding plane parallel hydrothermal silica vein

***Van den Boorn et al, 2007**

Microbial habitats



Coarser volcanic particles (surfaces/pore spaces)

Fine grained volcanic dust (pore space)

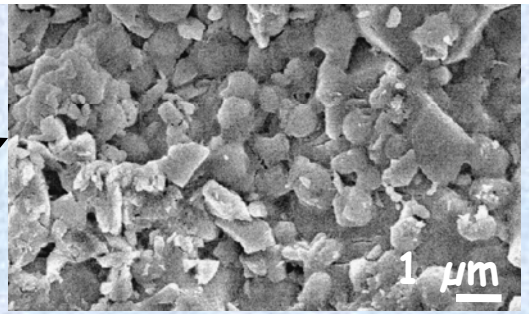
Pumice (surfaces/pore spaces)

Stable sediment surface

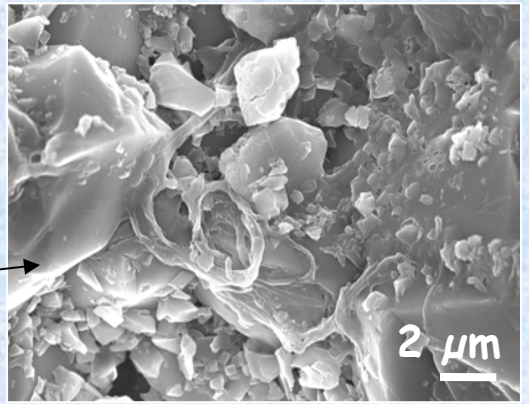
Volcanic particles (surfaces/pore spaces)

Microbial habitats and fossil microorganisms

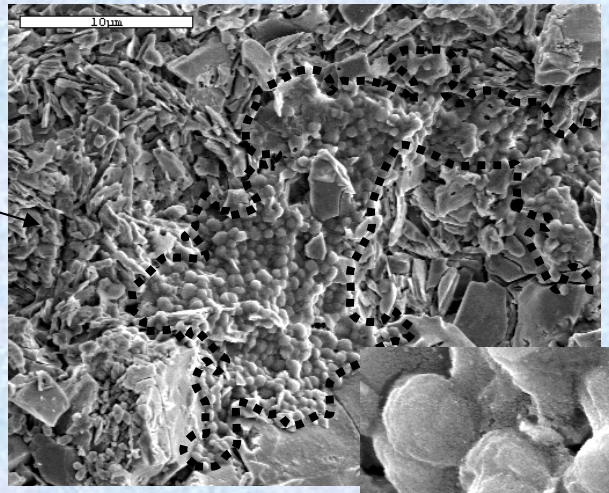
Small, microbial colonies

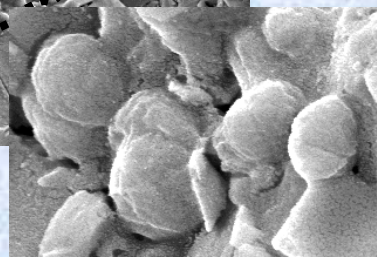


Biofilm



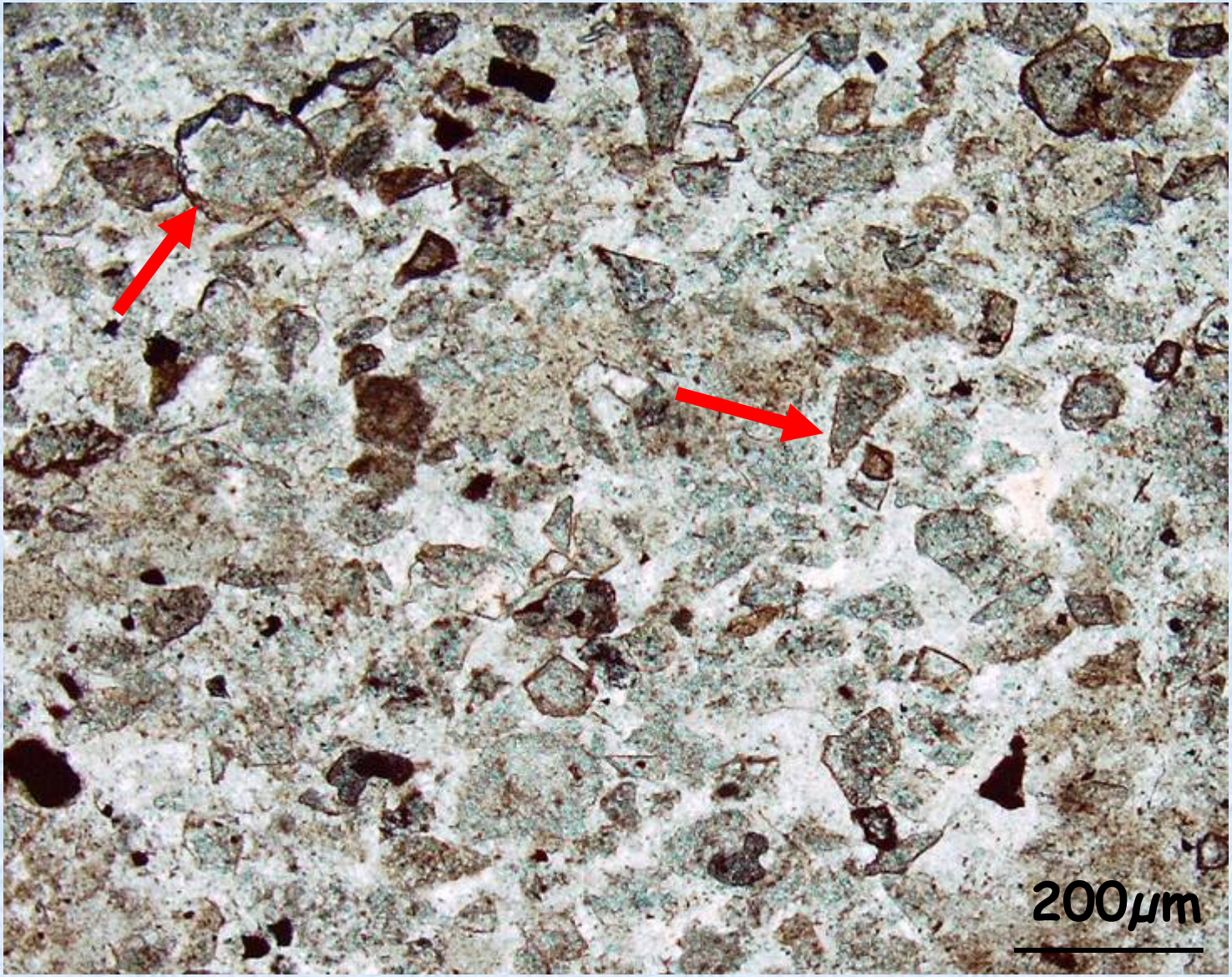
Small microbial colonies

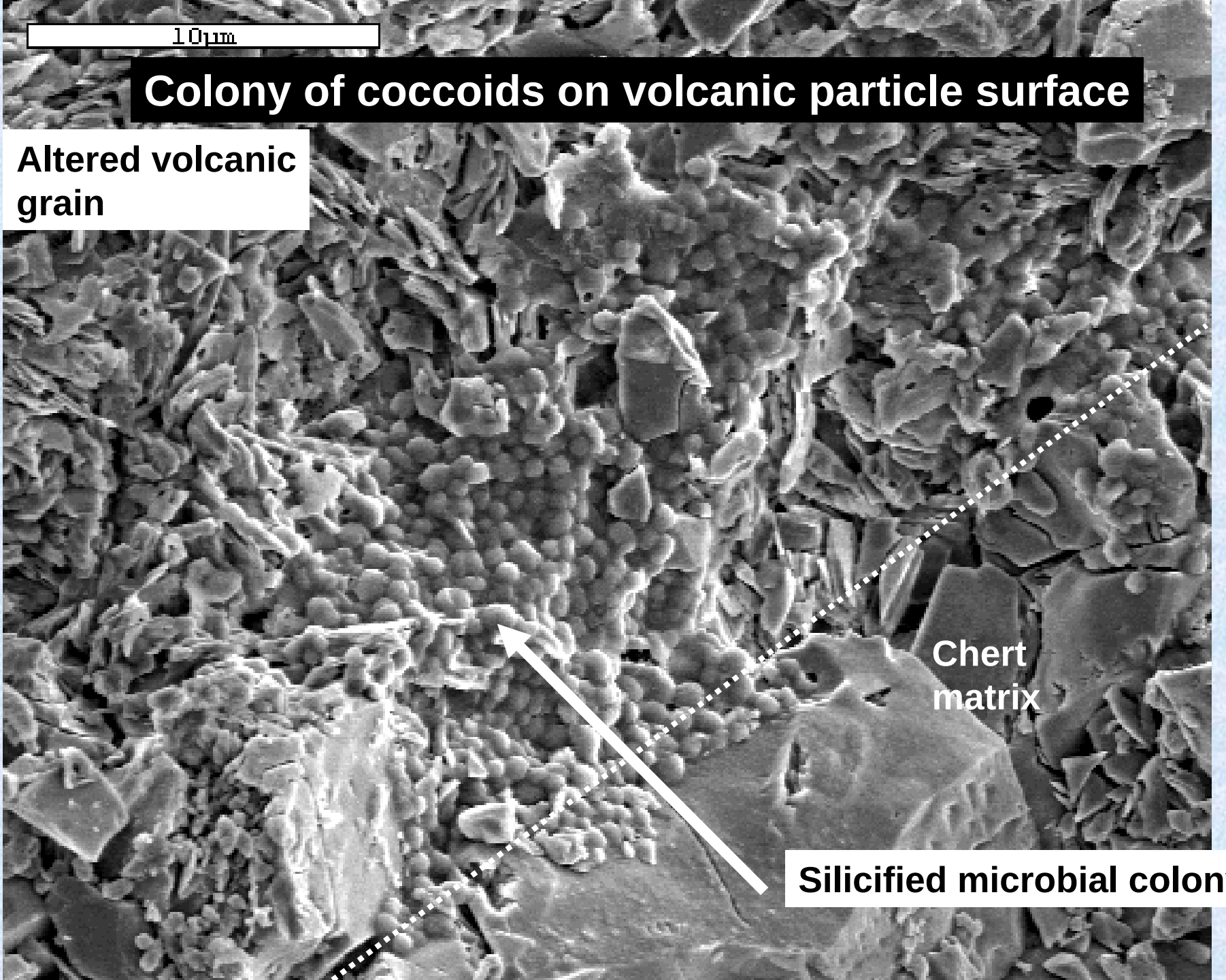


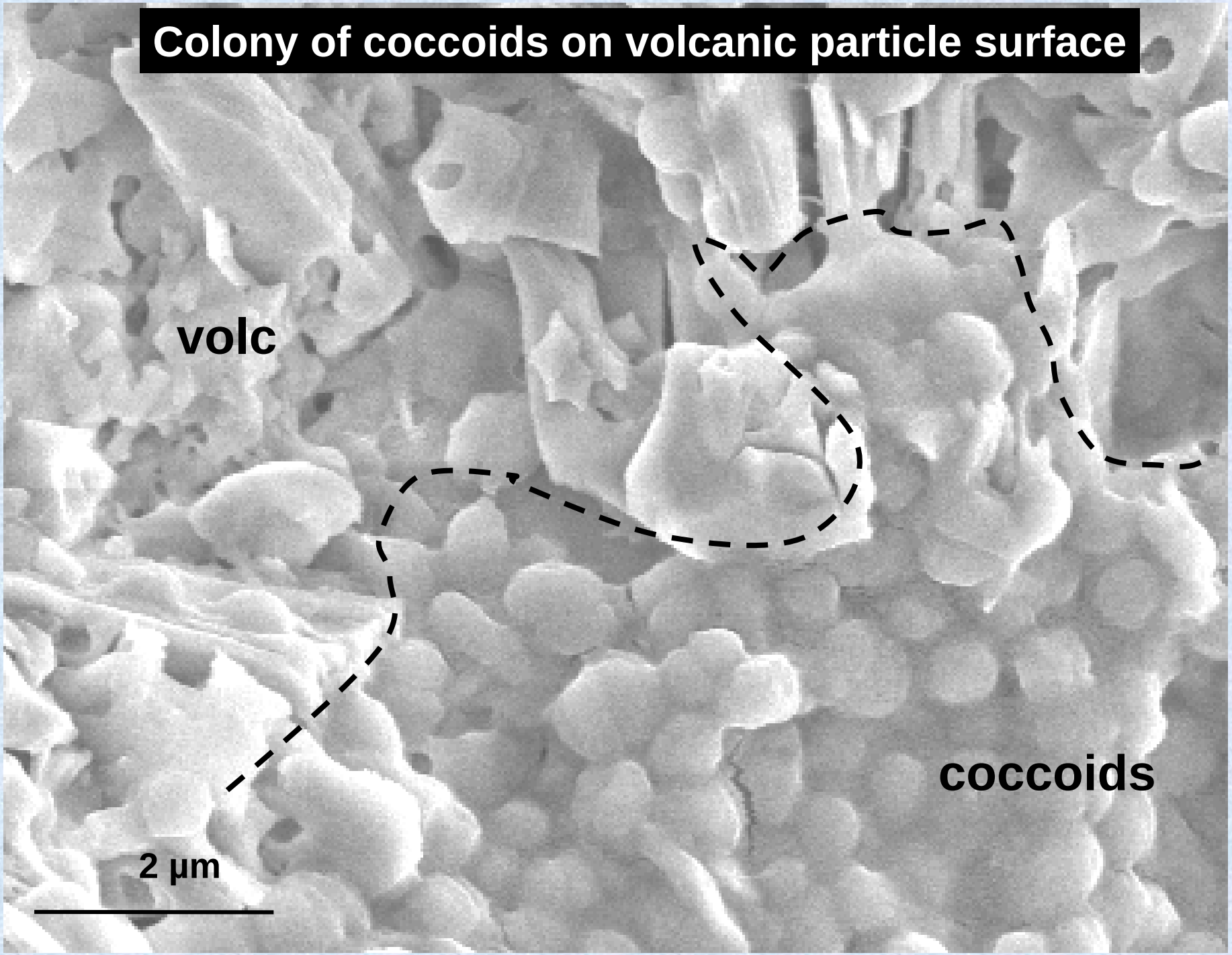


Fine volcanic sand

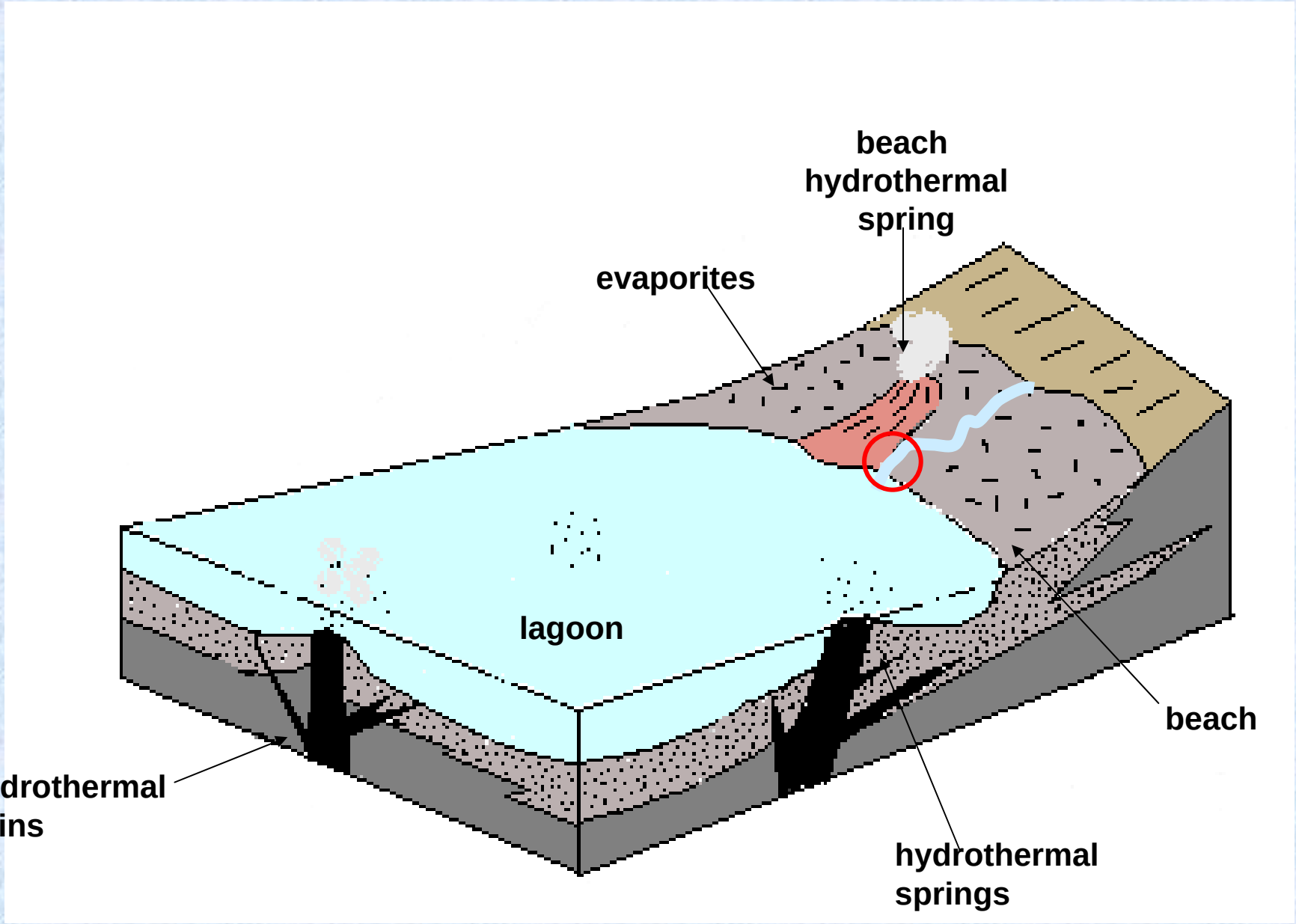
Volcanic particle surfaces



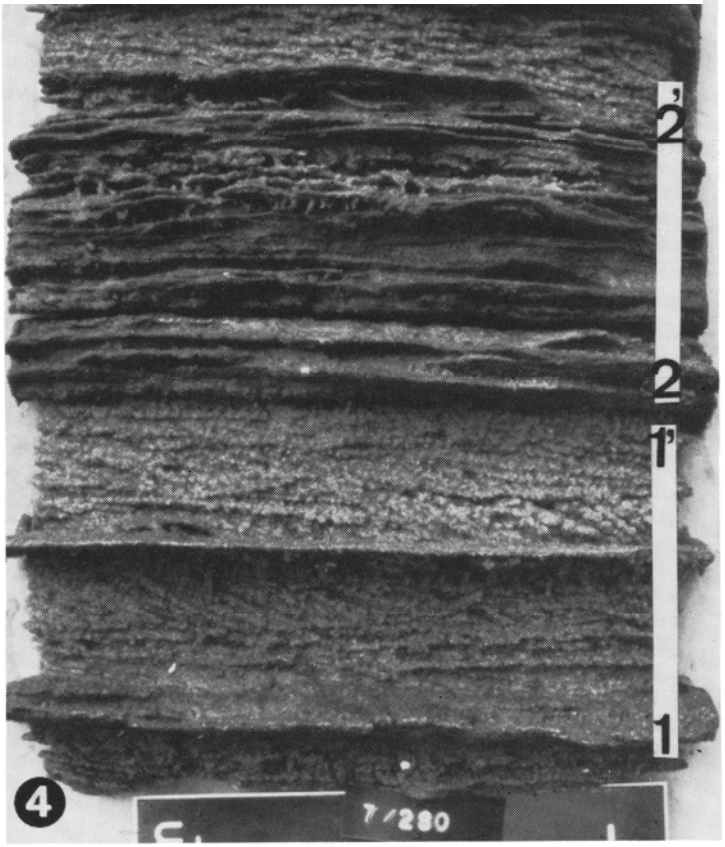

10µm
Colony of coccoids on volcanic particle surface
Altered volcanic grain
Chert matrix
Silicified microbial colony

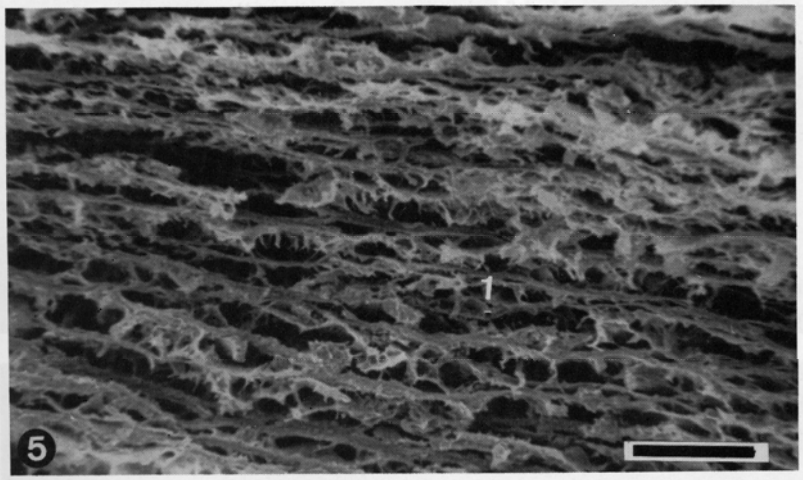

Colony of coccoids on volcanic particle surface
volc
coccoids
2 µm

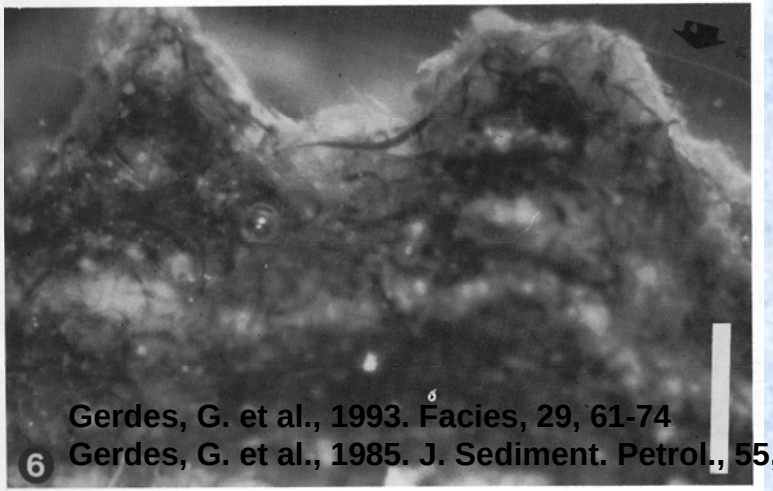
Littoral environment (photic zone)



Modern analogue: biolaminated sediments on a tidal flat





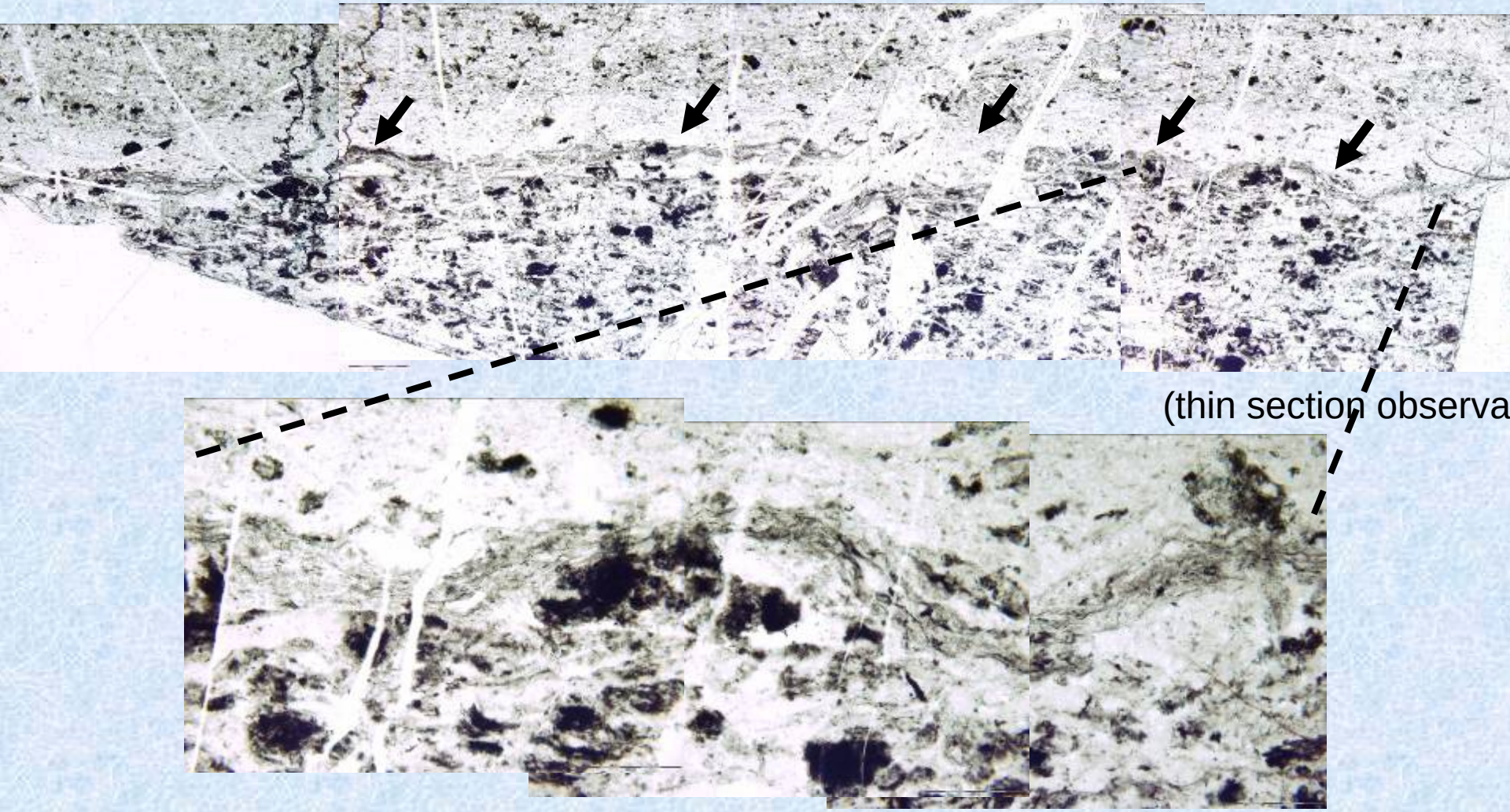


Gerdes, G. et al., 1993. Facies, 29, 61-74
Gerdes, G. et al., 1985. J. Sediment. Petrol., 55, 265-278

Example: Josefsdal Chert, Barberton ~3.3 Ga

Westall, F., et al. (2001, 2006, 2011).

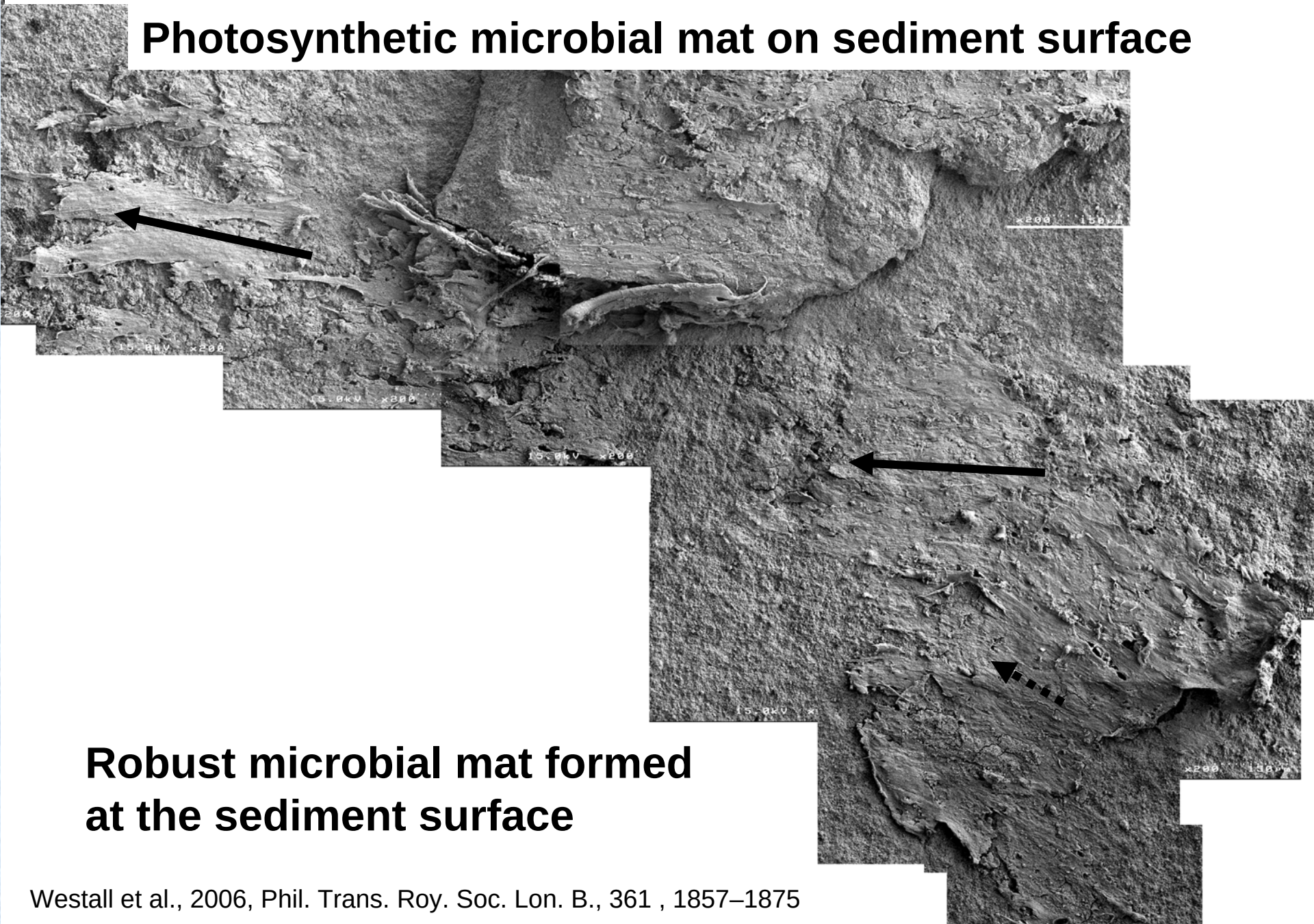
Example: Josefsdal Chert, Barberton ~3.3 Ga
Photosynthetic microbial mat on sediment surface



Finely laminated, wispy, wavy dark laminae conformable with the underlying topography embedded particles

Example: Josefsdal Chert, Barberton ~3.3 Ga

Photosynthetic microbial mat on sediment surface

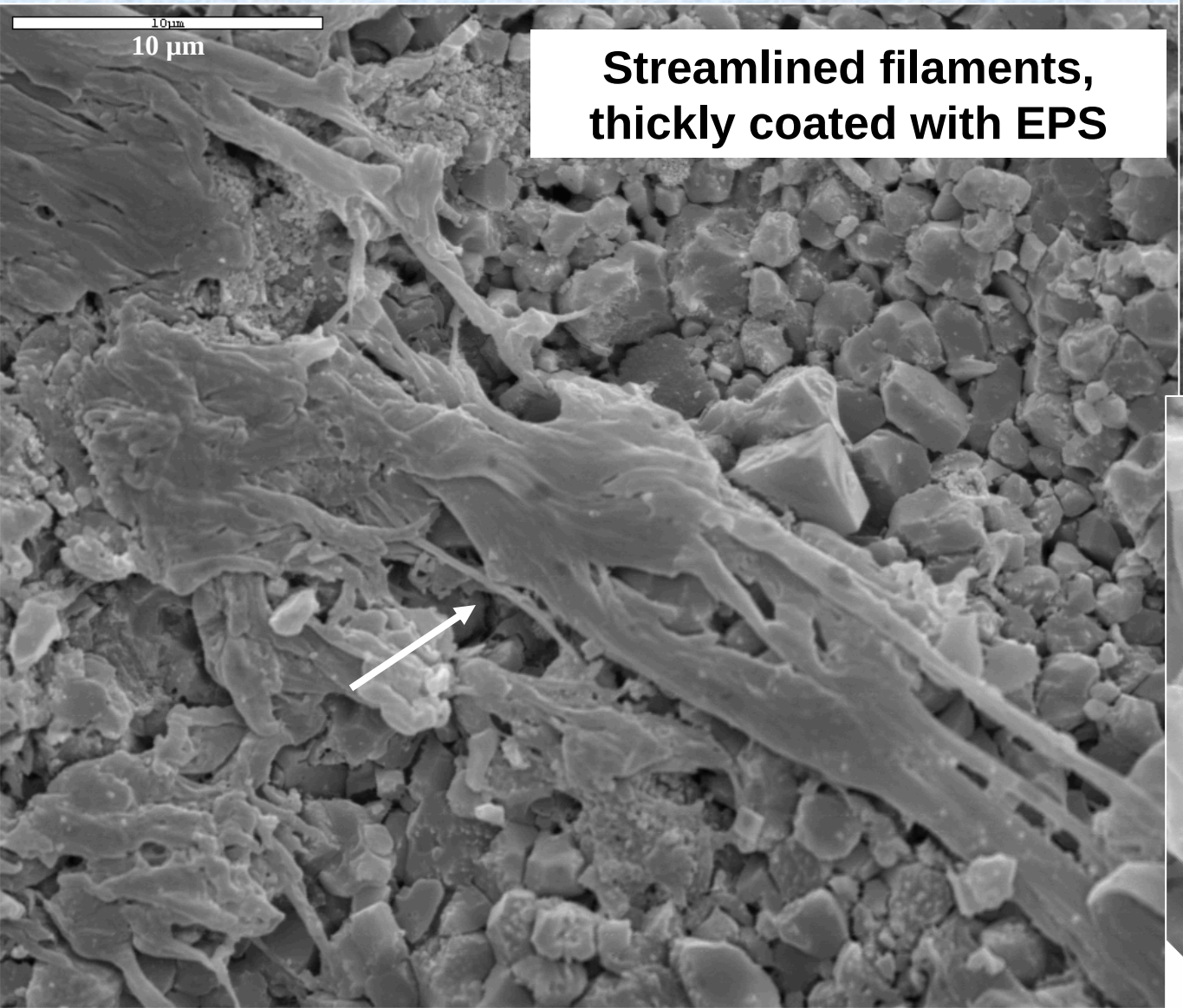


Robust microbial mat formed at the sediment surface

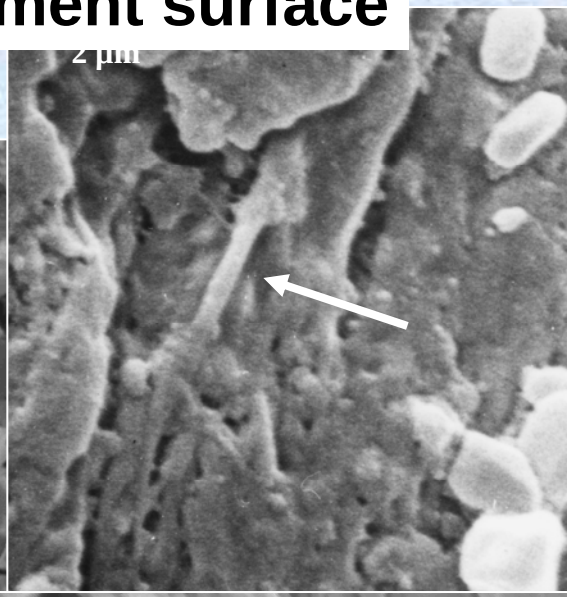
Westall et al., 2006, Phil. Trans. Roy. Soc. Lon. B., 361 , 1857–1875

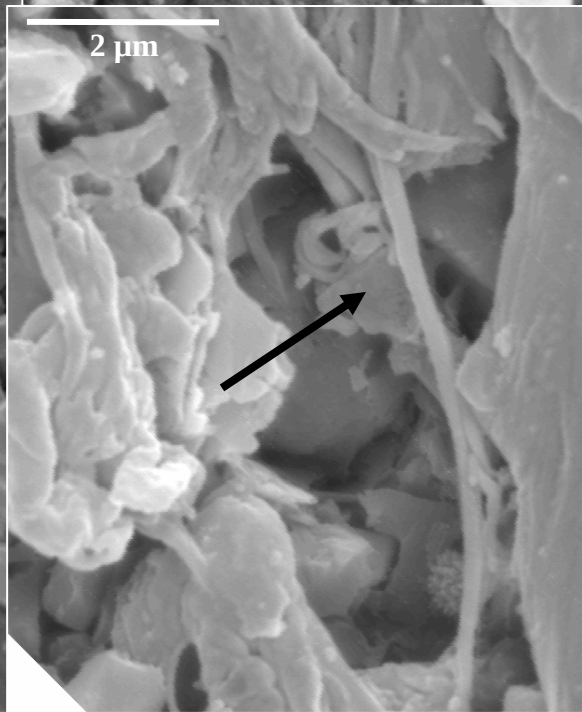
Example: Josefsdal Chert, Barberton ~3.3 Ga

Photosynthetic microbial mat on sediment surface

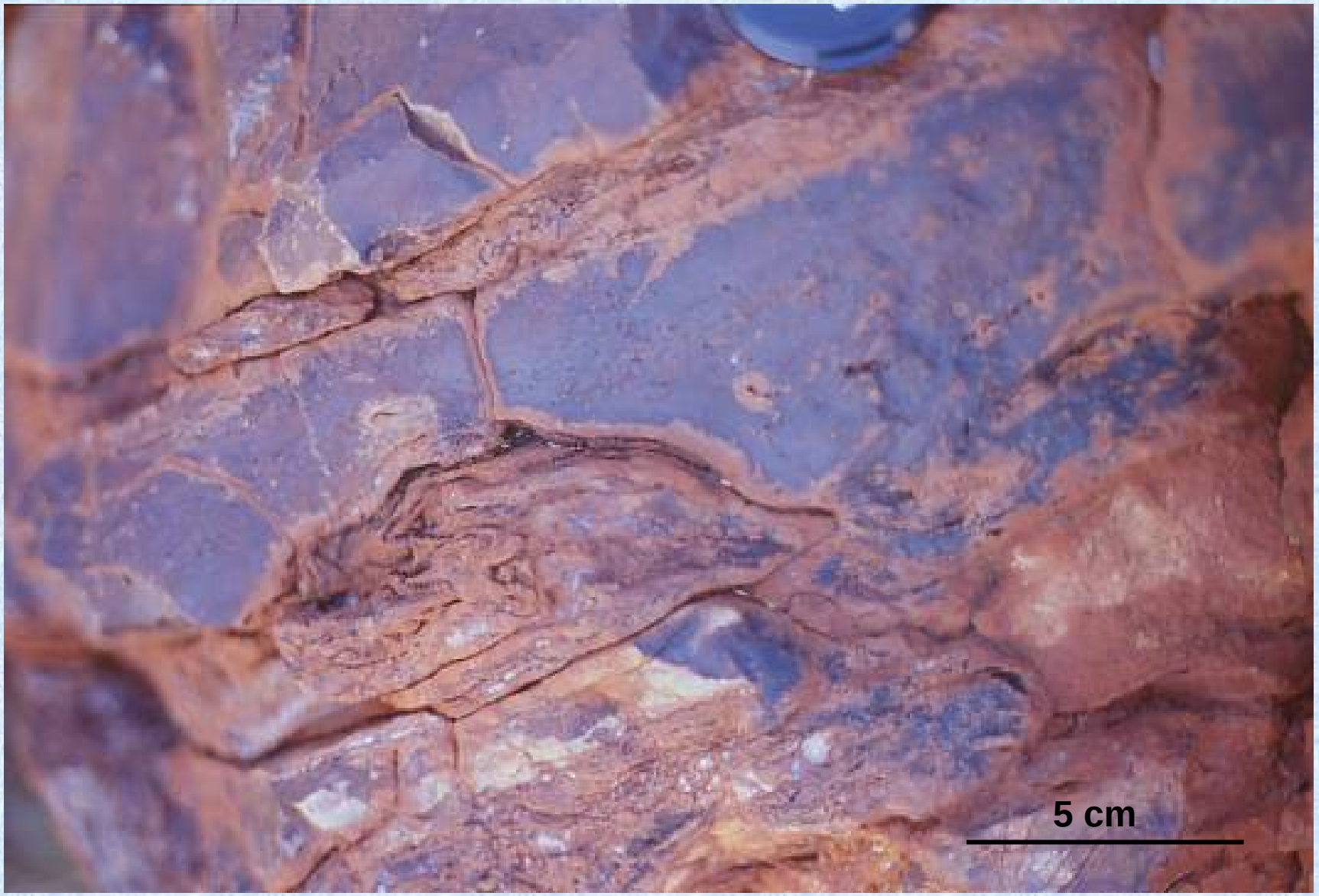


Streamlined filaments, thickly coated with EPS

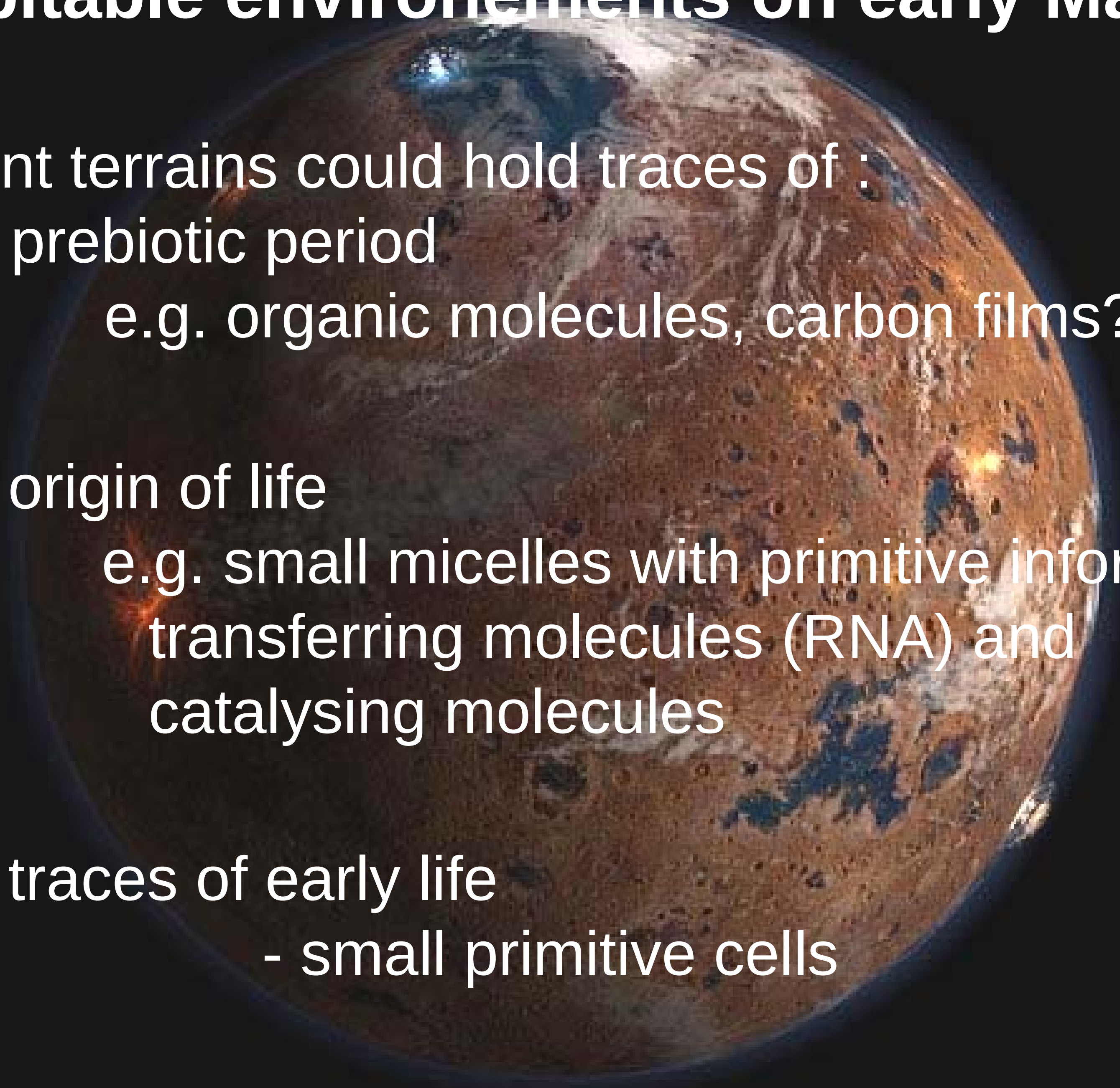




3.45 Ga stromatolite (photosynthetic microbial mat) (Pilbara, Australia)



Habitable environements on early Mars



→Ancient terrains could hold traces of :

- prebiotic period

  e.g. organic molecules, carbon films?

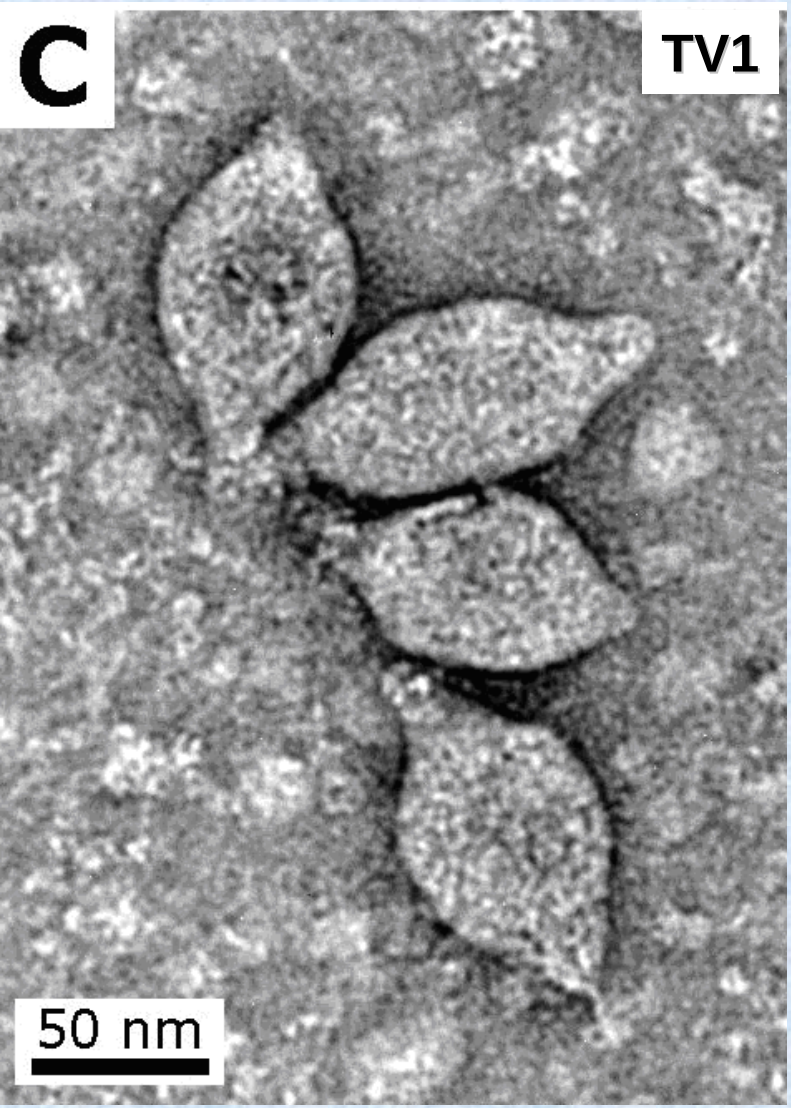
- origin of life

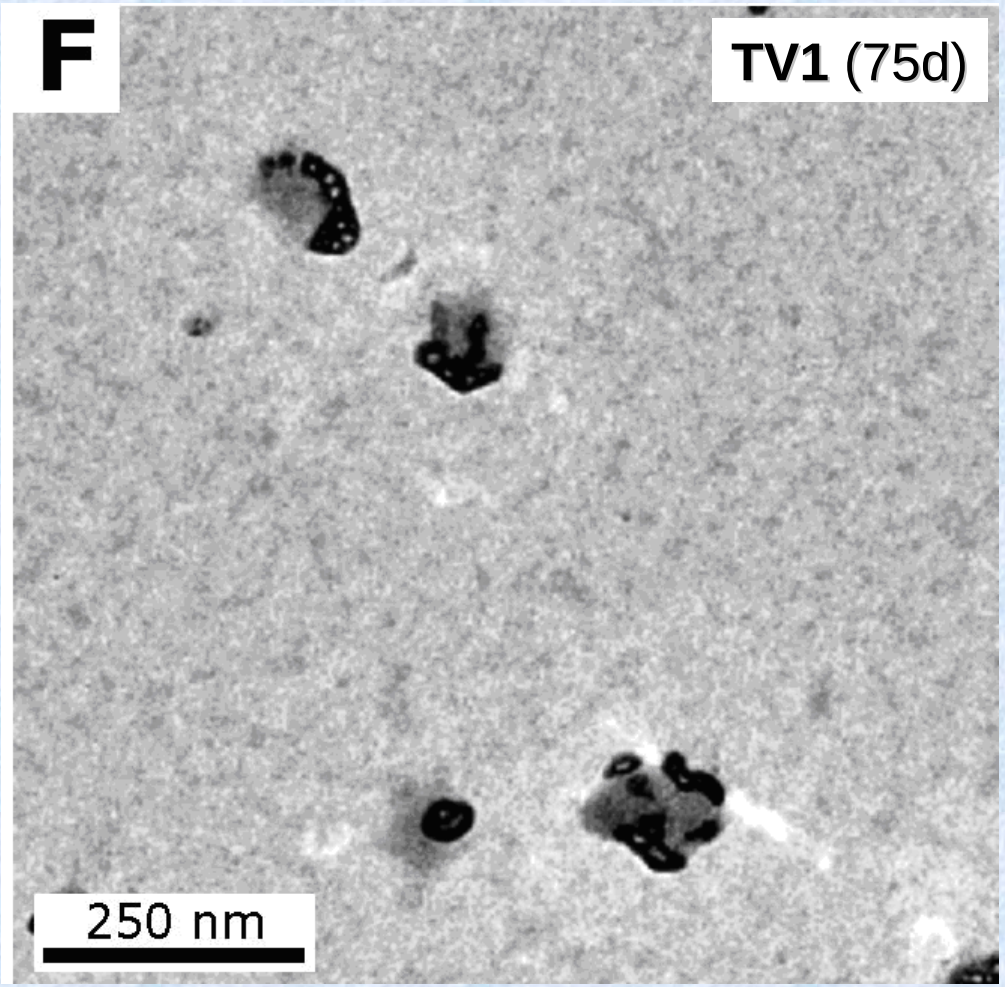
  e.g. small micelles with primitive information-transferring molecules (RNA) and catalysing molecules

- traces of early life

  - small primitive cells

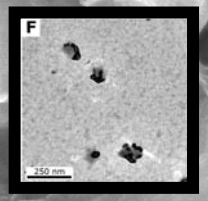
Small cells - fossilised viruses

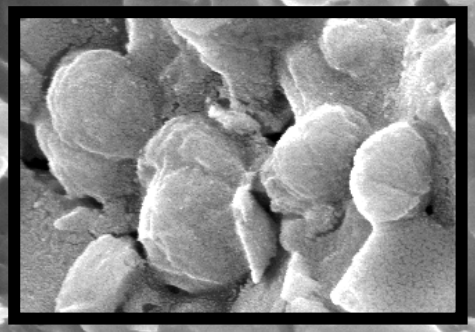




Orange, Westall et al.
Biogeosciences, 8, 1465–1475, 2011

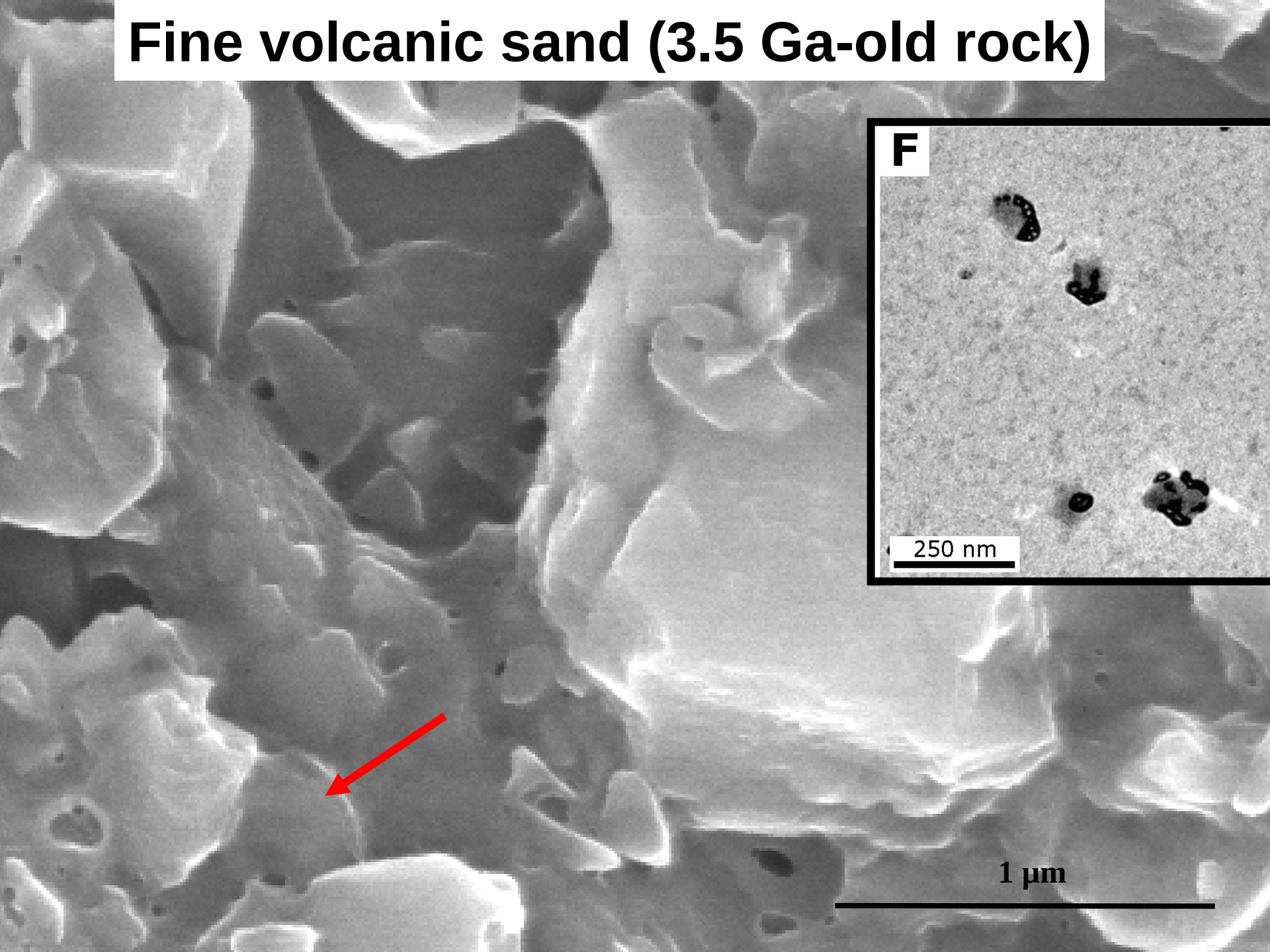
Fine volcanic sand (3.5 Ga-old rock)





1 µm

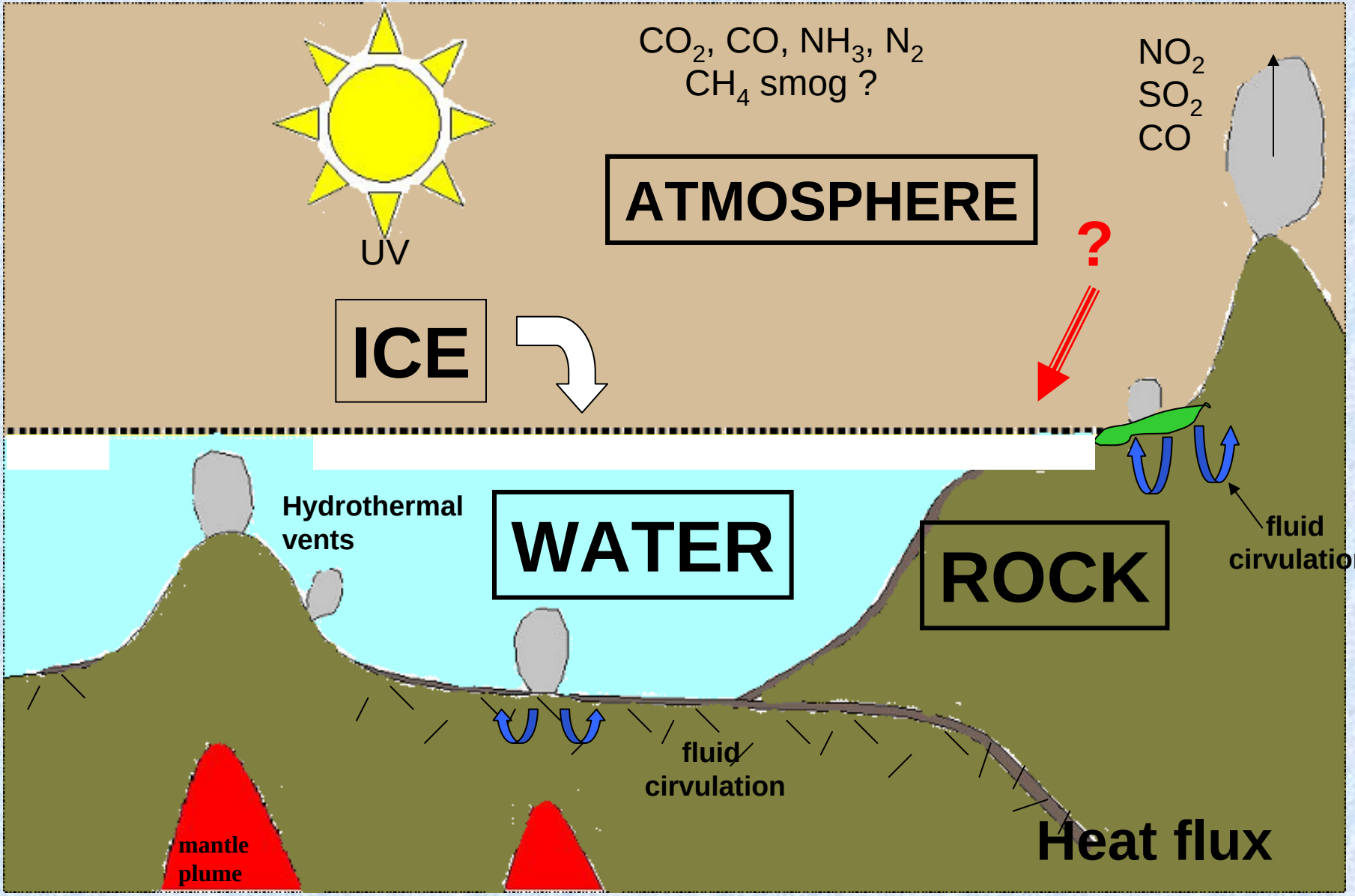
Fine volcanic sand (3.5 Ga-old rock)



Habitable environments on the early Mars

Habitats	Energy (E) and Carbon (C) sources	Organism types
Hydrothermal vents/springs (deep, shallow)	C/E from inorganic/organic sources,	Thermo-mesophilic chemolithotrophs/ organotrophs
Deep sea floor: sediments; crustal cracks; Lava surfaces	C/E from inorganic/organic sources	Thermo-mesophilic chemolithotrophs/ organotrophs
Littoral environments (photic zone); sediments; lava surfaces,	C/E from inorganic/organic sources, E from sunlight	Thermo-mesophilic chemolithotrophs/ organotrophs/ Phototrophs ?
Water column??	C/E from organic sources, E from sunlight	Phototrophs ? Organotrophs ?

Habitats on the early Mars



Biosignatures

Major microbial components	Biosignature	Specific component or structure	
Cell components	***Carbon molecules (kerogen)***	composition structure	odd/even C number µ-structure
Cell metabolic activity	***Biominerals***	direct (*e.g.* magnetite) indirect (*e.g.* microcrystalline calcite, aragonite, dolomite)	
	Elements	concentration	*e.g.* Ni, Cu, Mn, Co, Mo, Se, V, Fe
		isotopic ratios	*e.g.* C, O, S, N, P, Fe
	Microbial influence on:	mineral composition mineral habit mineral dissolution mineral size	
Cell colonies, biofilms, mats, EPS	***Fossil cells, colonies, mats***	Clotted fabrics microbial mounds biolaminites	stromatolites MISS*