Microbes & Evaporites

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cost
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

MedSalt

Microbiology and the foundations & beauty of Salamanca

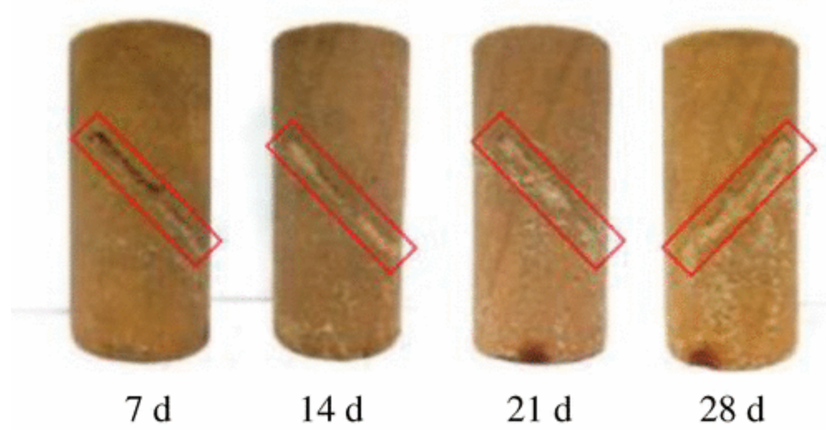
Eocene Villamayor Sandstone (Golden stone); when quarried it appears “blond”

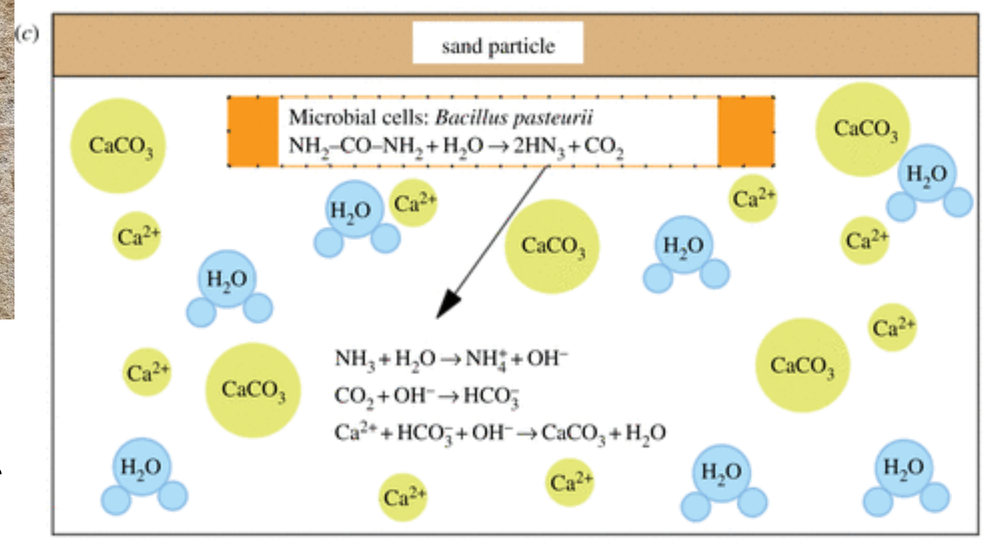
Garcia-Talegón J et al. (2015) In: Pereira D et al. (eds) Global Heritage Stone: Towards International Recognition of Building and Ornamental Stones. Geol Soc Spec Publ Lond 407:109–120.

Porous, so a terrible foundation stone, but depends on relative humidity (water activity, A_w) – see Jain A et al. (2009) Build Environ 44:1276–1284

Microbiology and the foundations & beauty of Salamanca

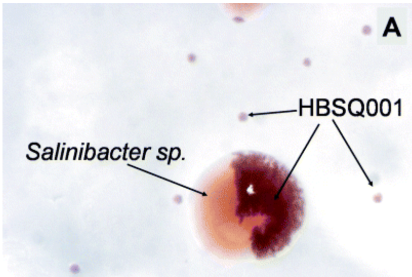
- Why does it deteriorate and form an array of colours?
  - physical, chemical & microbiological processes (microbial biofilms and hydrophobicity, photosynthetic activity, Fe-cycling, acid-producers, mineral producers etc.)

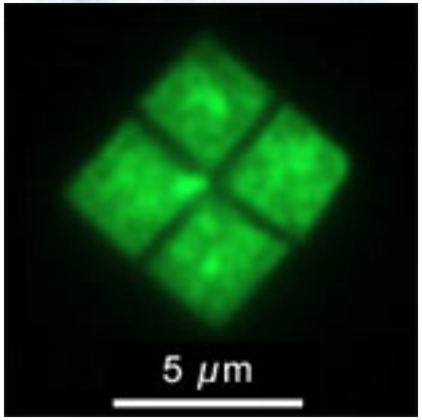




•Possible to use microbes to repair biodeterioration, e.g. microbes like *Bacillus pasteurii* precipitate calcium carbonate as cement? – see Gao et al. (2019) Royal Soc Open / doi.org/10.1098/rsos.191318

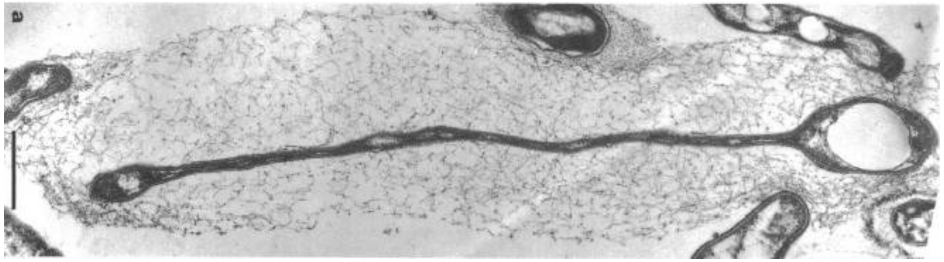
- What are microbes & how were/are they important for planet Earth?
- Genetic diversity
- Metabolic diversity
- Microbes in extremis
- Microbes in hypersaline environments & evaporites

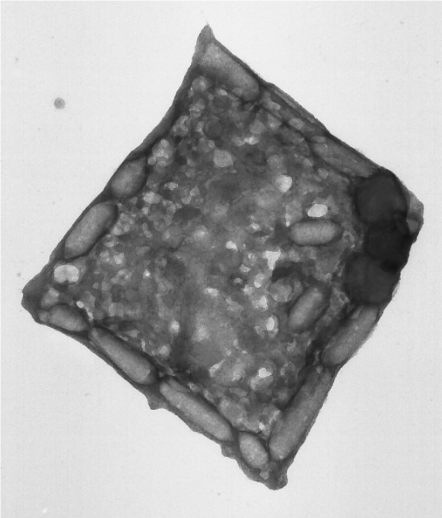




- **Beer for the most “stupid” question!**
- **Favourite microbe?**

Haloquadratum walsbyi





Bolhuis H *et al.* (2004) *Environ Microbiol* 6: 1287-1291. Kessel M, Cohen Y (1982) *J Bact* **150:** 851-860

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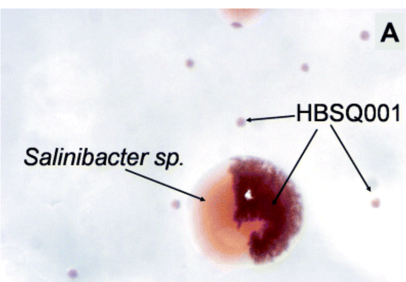

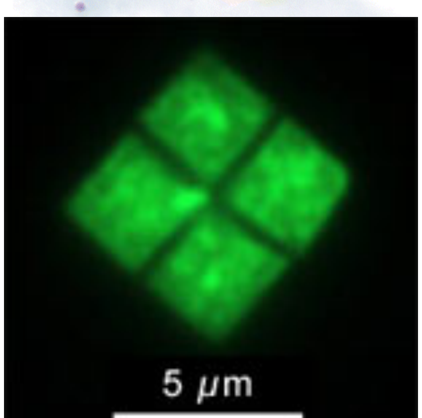

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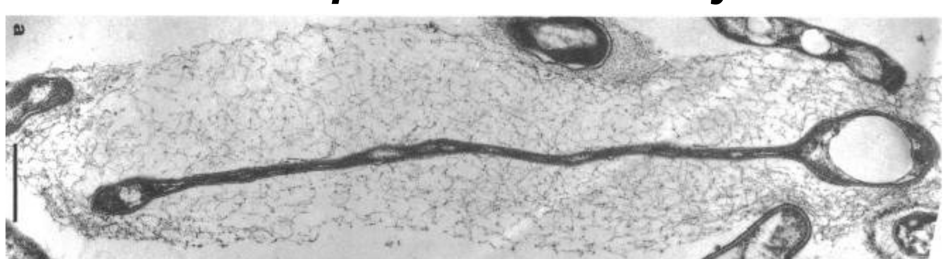

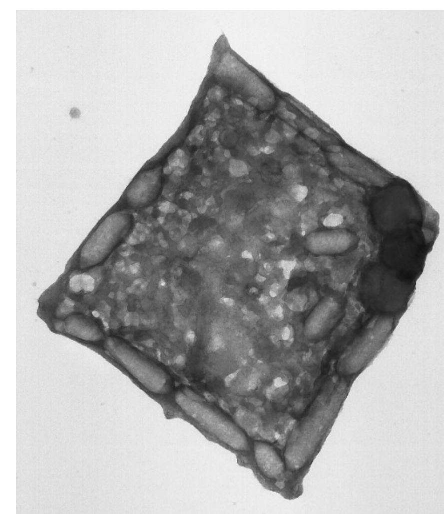

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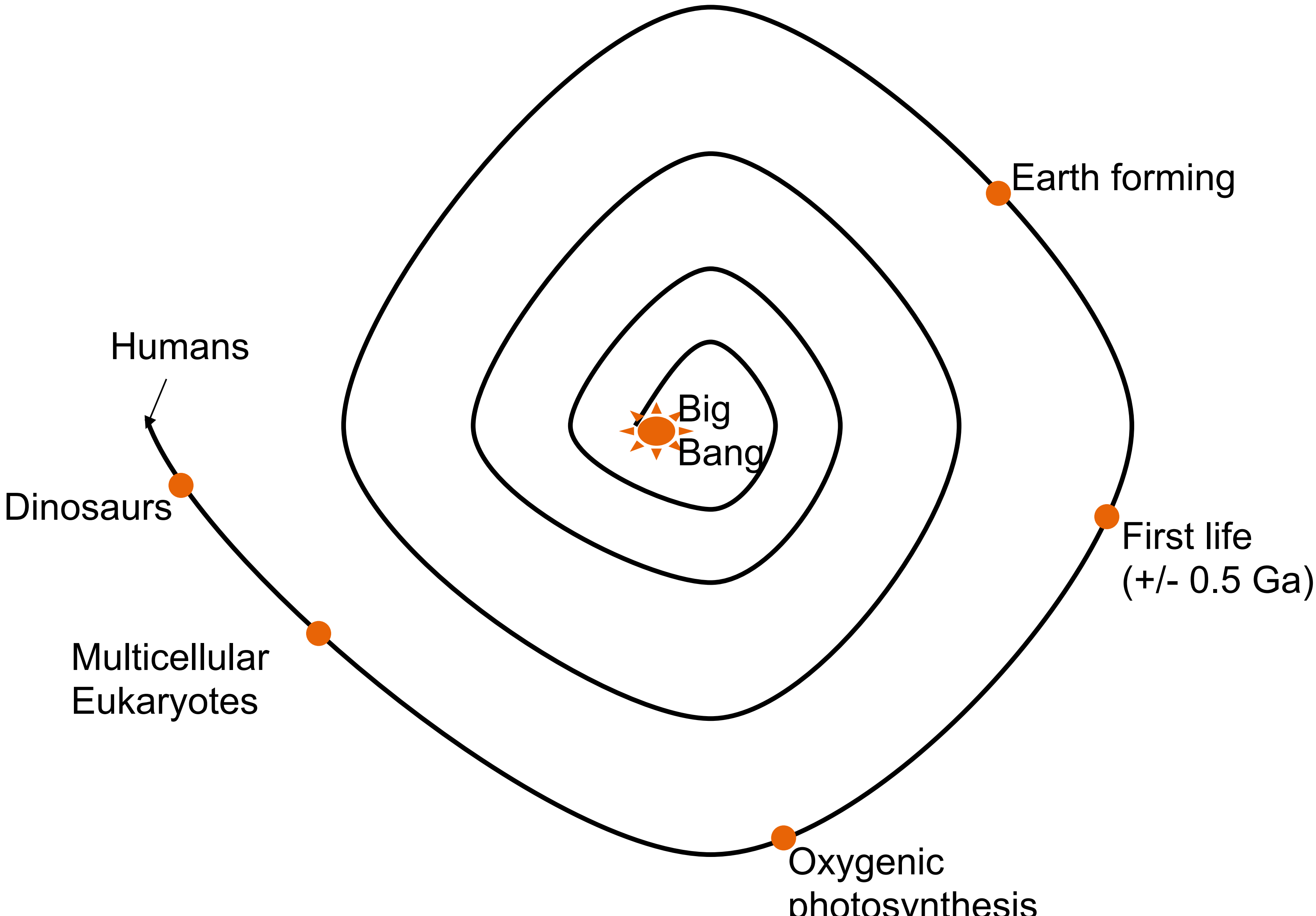
Features of microorganisms that make them important for our planet

- On Earth for at least 3.5 billion years

80% of natural history is about the natural history of microbes

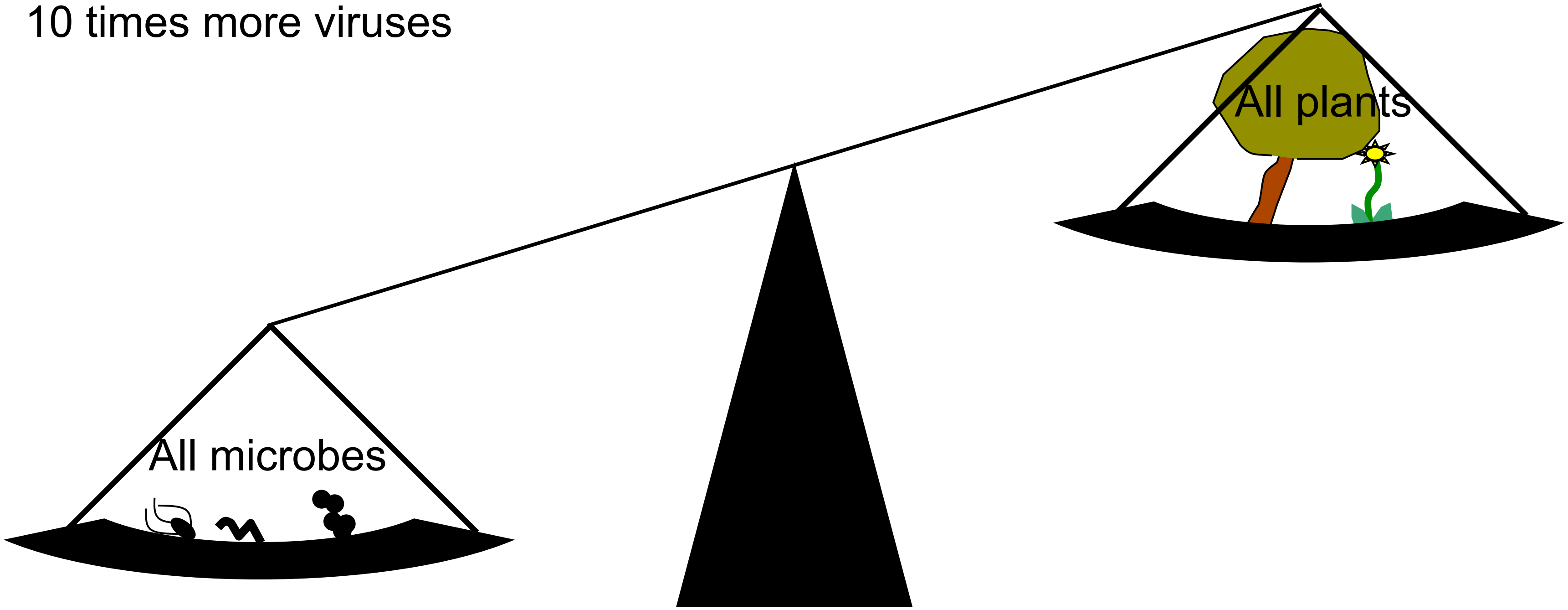


Features of microorganisms that make them important for our planet

- On Earth for at least 3.5 billion years
- Abundant

Microbes are abundant

10^{29} – 10^{30} microbes on and in the earth
10 times more viruses



Whitman WB, Coleman DC &Wiebe WJ (1998) Prokaryotes: the unseen majority. *PNAS* 95: 6578-6583. [revised down slightly by Kallmeyer J et al. (2012) *PNAS* 109: 16213–16216]

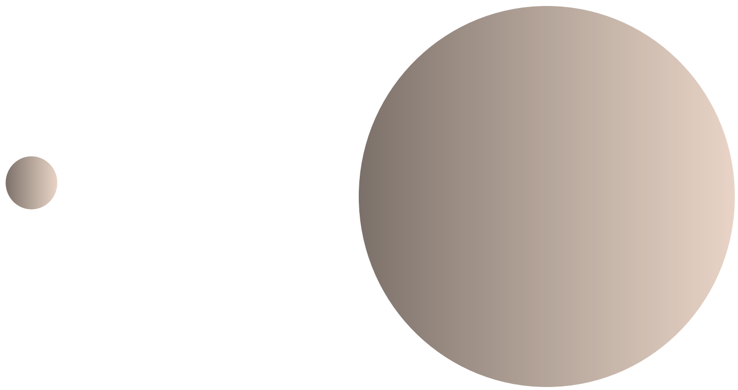
Features of microorganisms that make them important for our planet

- On Earth for at least 3.5 billion years
- Abundant
- Small

Typical bacterial cell is ~ 0.001 mm (100th the width of human hair)

Features of microorganisms that make them important for our planet

- On Earth for at least 3.5 billion years
- Abundant
- Small, with a large, proportionally reactive surface



r = 0.5 µm
SA / V = 6

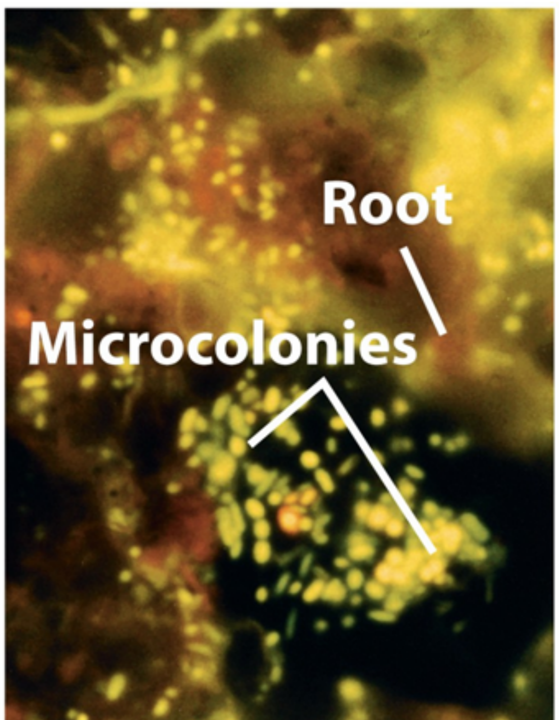
r = 5 µm
SA / V = 0.6

Features of microorganisms that make them important for our planet

- On Earth for at least 3.5 billion years
- Abundant
- Small, with a large, proportionally reactive surface
- Tolerate/require a huge range of physico-chemical extremes

Features of microorganisms that make them important for our planet

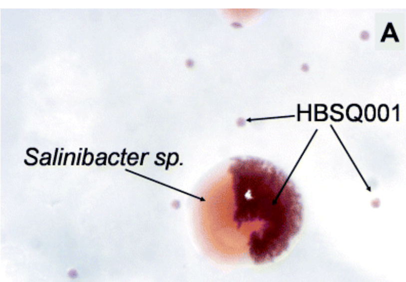
- On Earth for at least 3.5 billion years
- Abundant
- Small, with a large, proportionally reactive surface
- Tolerate/require a huge range of physico-chemical extremes
- Colonise every habitable part of the earth

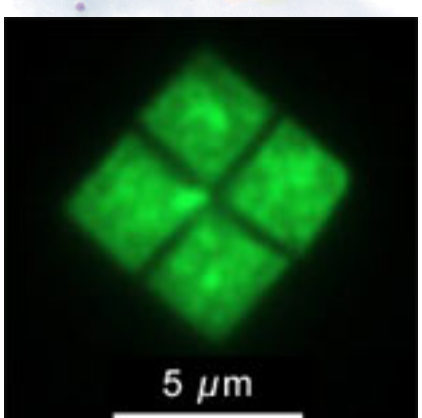


Frank Dazzo

Figure 19-3b Brock Biology of Microorganisms 11/e

- What are microbes & how were/are they important for planet Earth?
- **Genetic diversity**
- Metabolic diversity
- Microbes in extremis
- Microbes in hypersaline environments & evaporites





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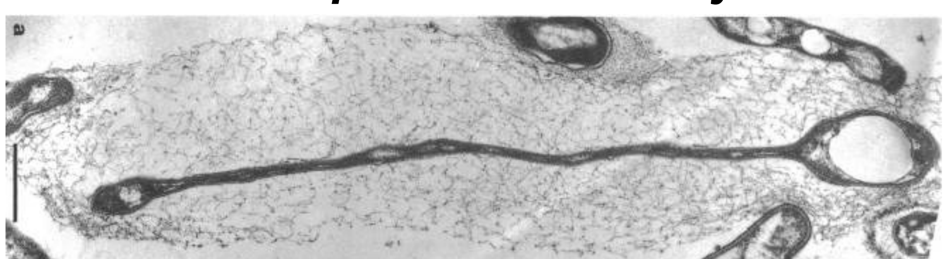

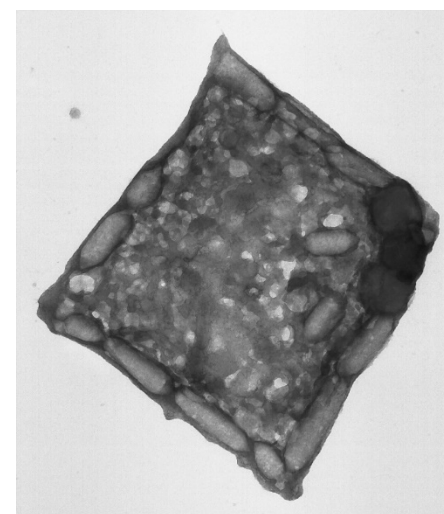

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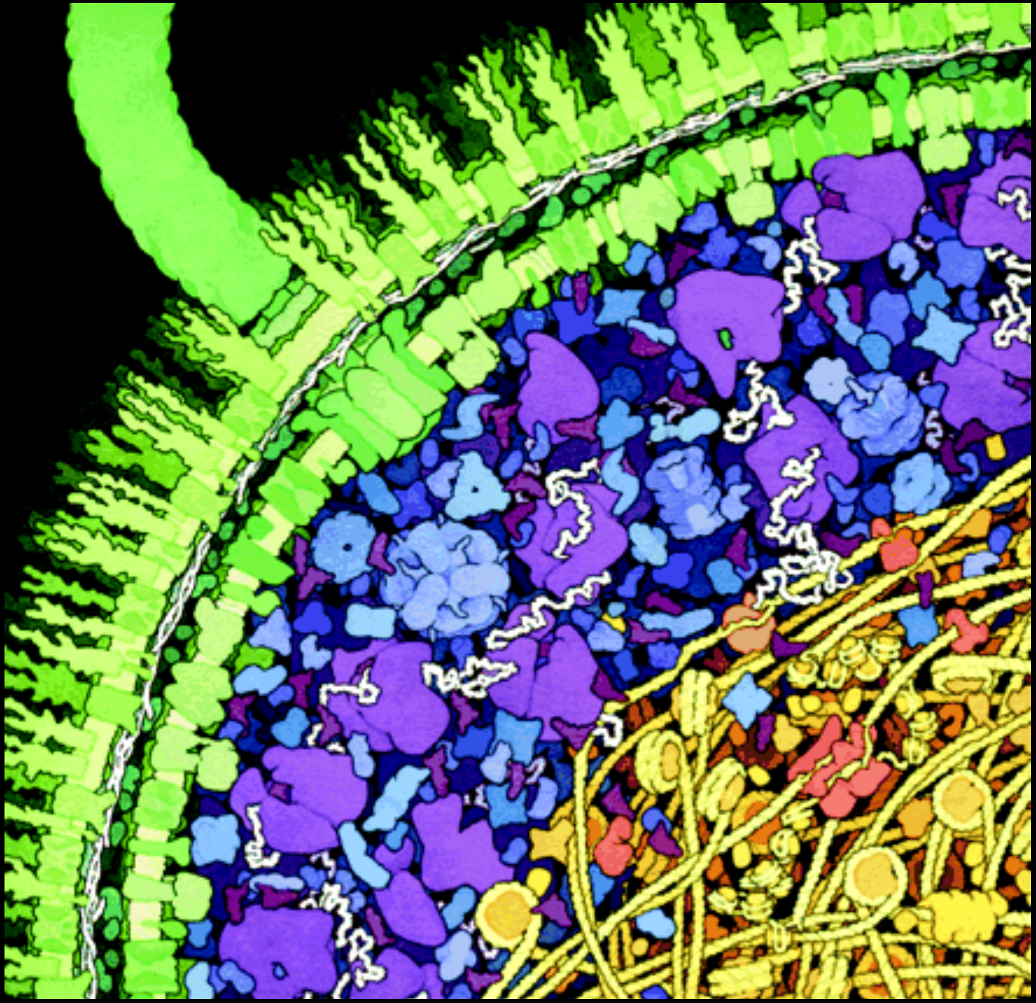
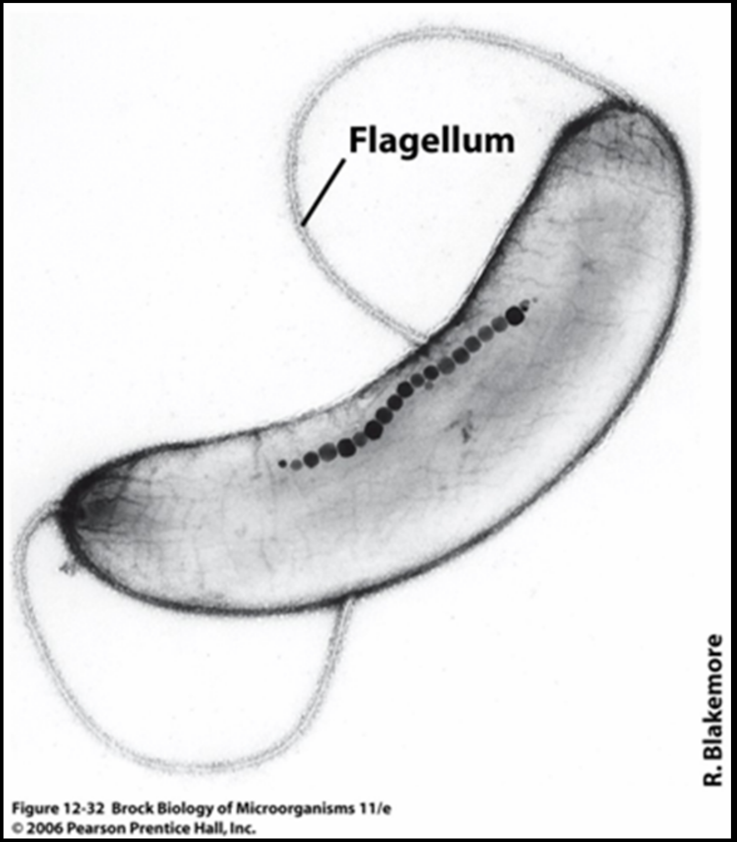




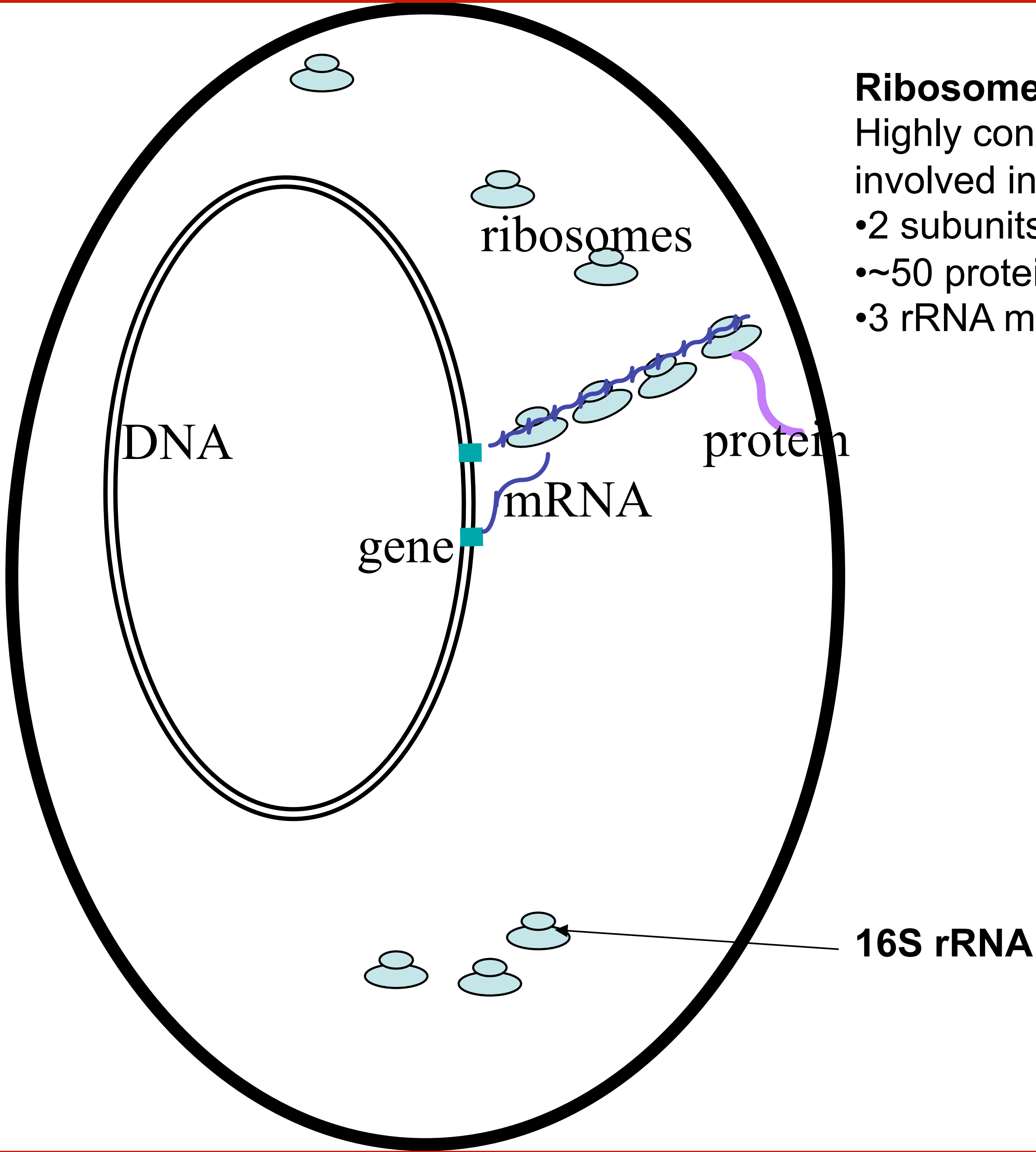
A cross section of an *Escherichia coli* cell

Cell wall, concentric membranes, transmembrane proteins, and a flagellum with its motor are shown in green

Cytoplasm is shown in blue and purple.

Nucleic acids are shown in yellow.

Reprinted with permission of David S. Goodsell, The Scripps Research Institute, La Jolla, CA. Pielak GJ (2005) A model of intracellular organization. PNAS USA

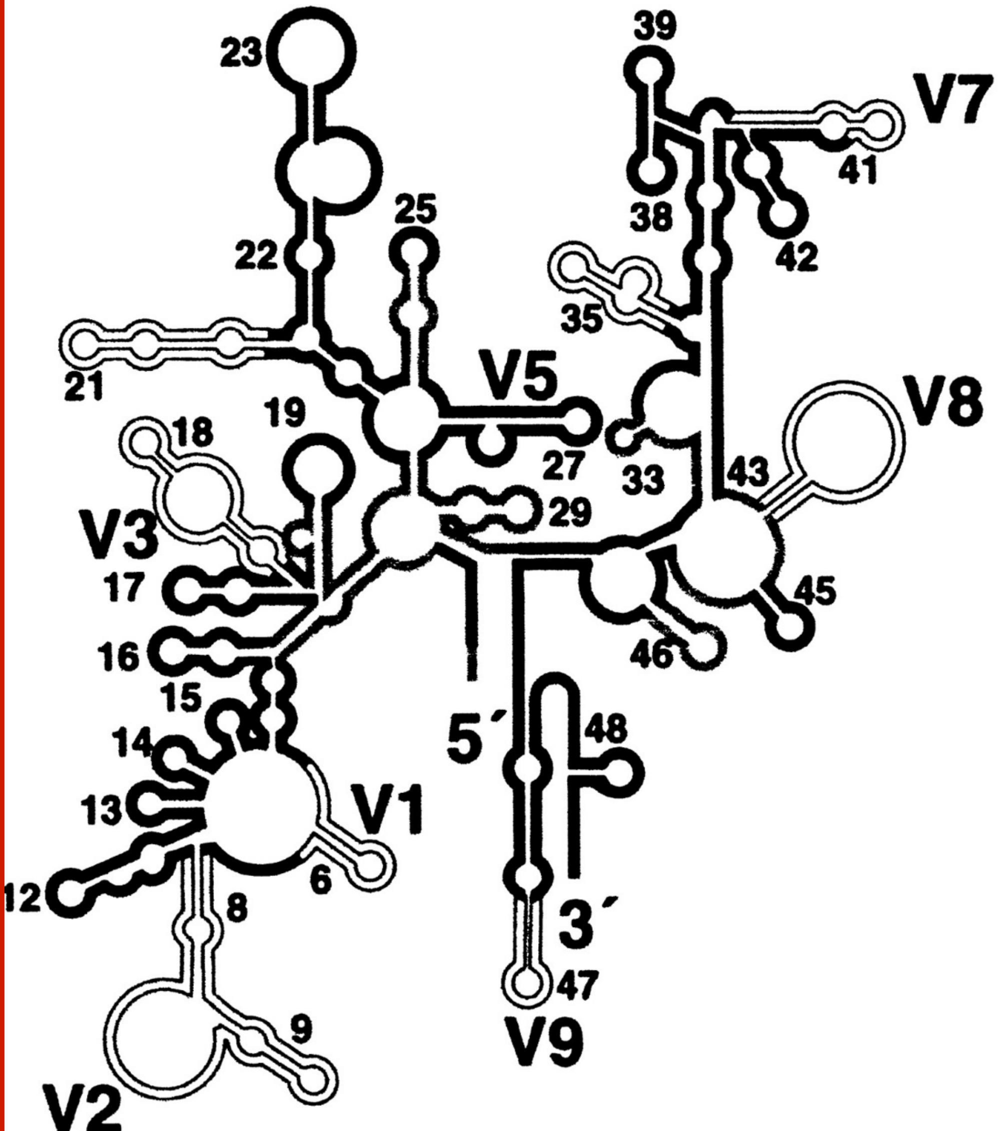


Ribosomes

Highly conserved organelles involved in protein synthesis

- 2 subunits
- ~50 proteins
- 3 rRNA molecules

16S rRNA molecule



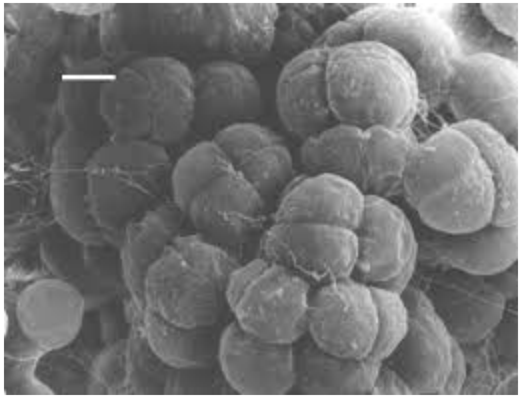
- All cells contain ribosomes that perform the same function
- Bacterial & Archaeal ribosomal RNA
  - **16S** (1500 nucleotides) = 18S in eukaryotes
- Highly conserved regions used for aligning
- Variable regions used to establish evolutionary distance
- Nucleotide sequences of rRNA (or its gene) can be compared to construct an evolutionary tree

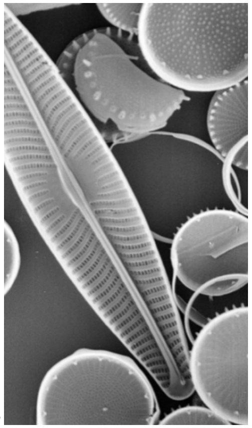
- white = variable or hypervariable
- black = highly conserved
- V1 to V9 = major variable regions

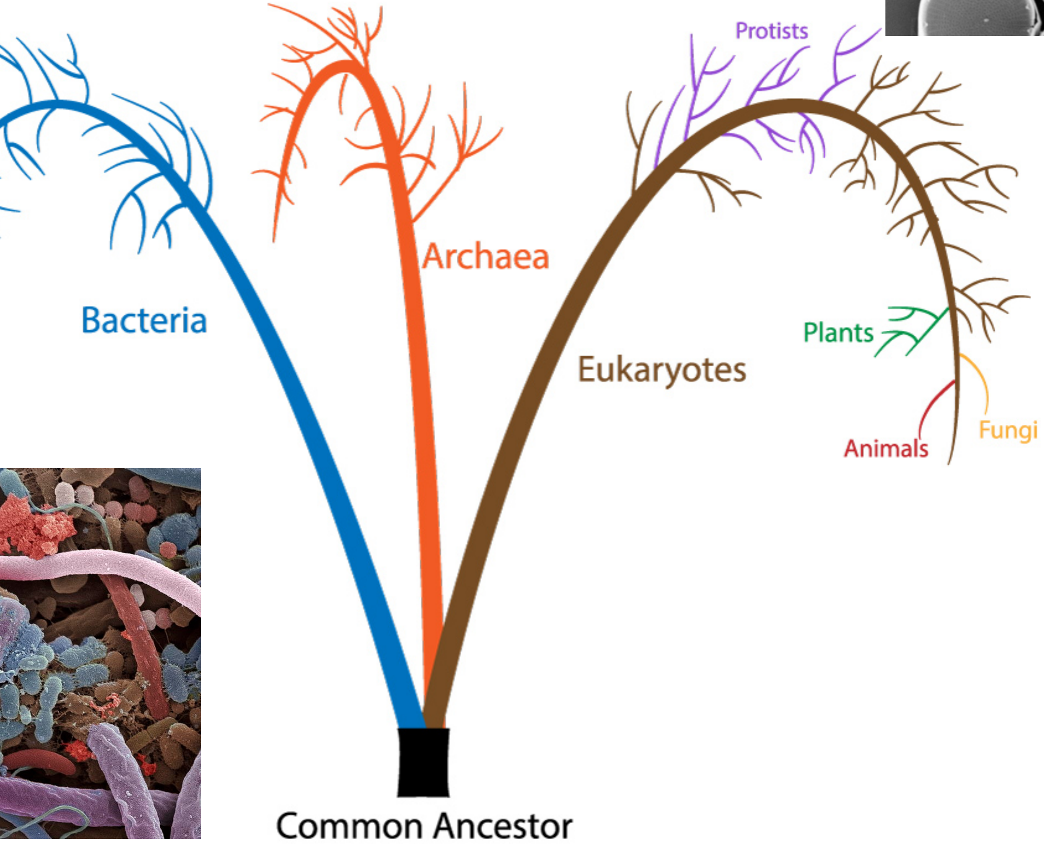
Enrico Tortoli Clin. Microbiol. Rev. 2003;16:319-354

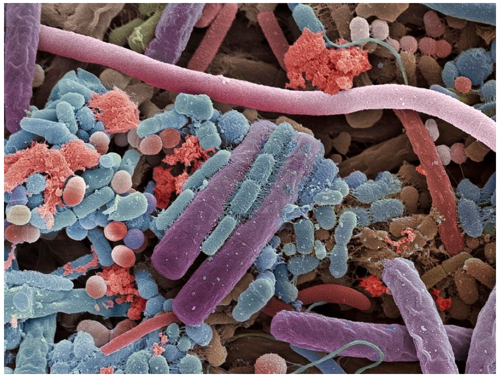
Microbes in the three Domains of life

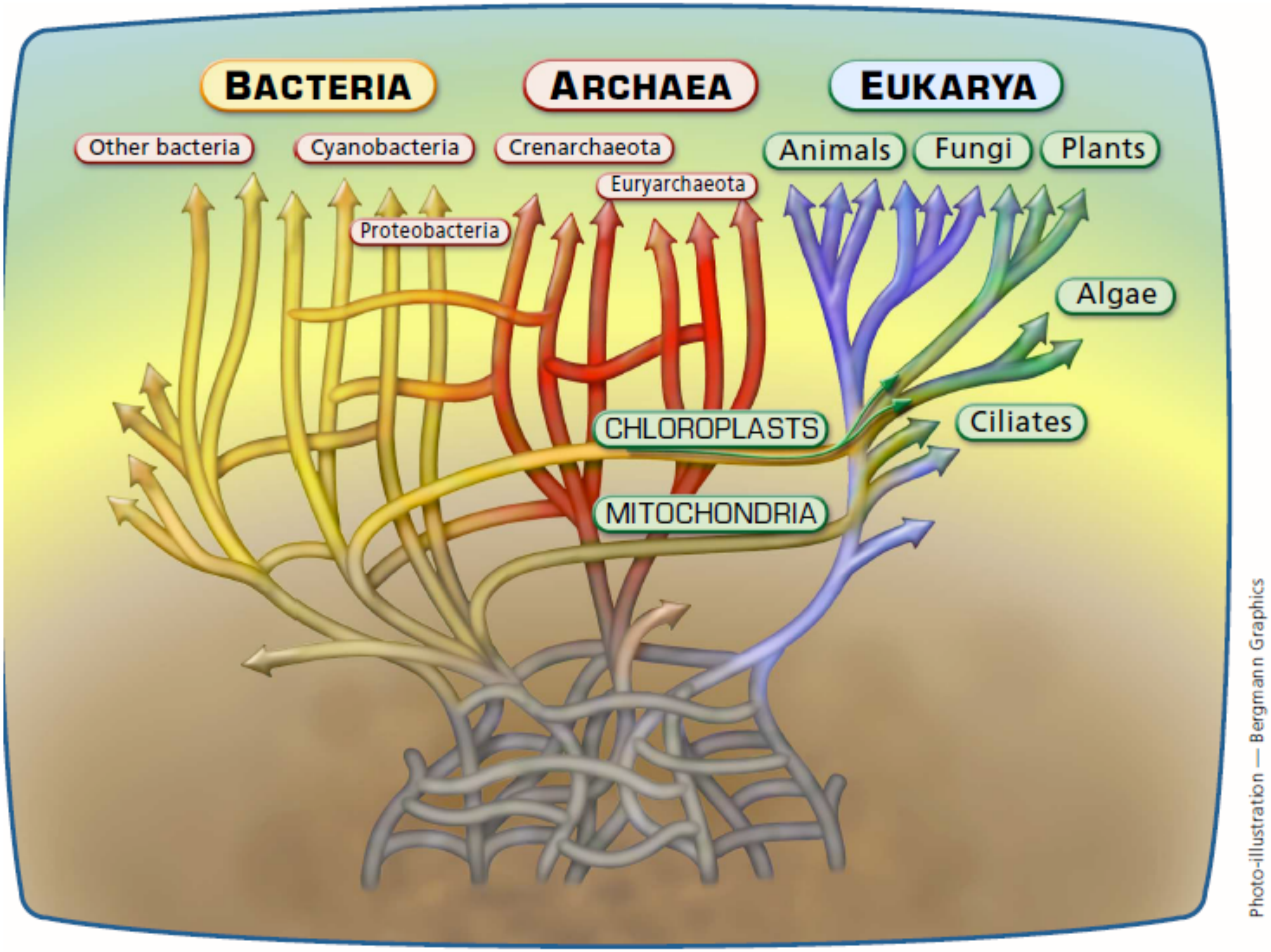
- Bacteria
- Archaea
- Most Eukaryotes





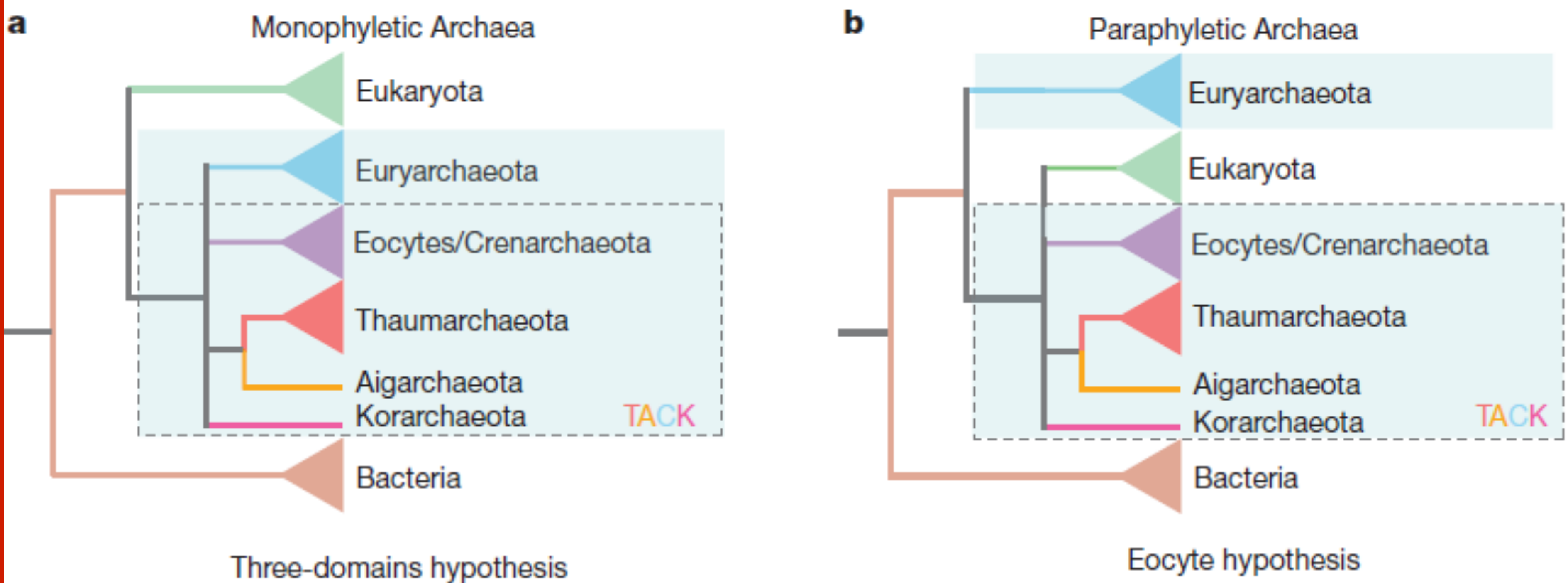






W. Ford Dolittle's schematic representation of evolution (not to scale)

An alternative / emerging view is the 2-domain tree



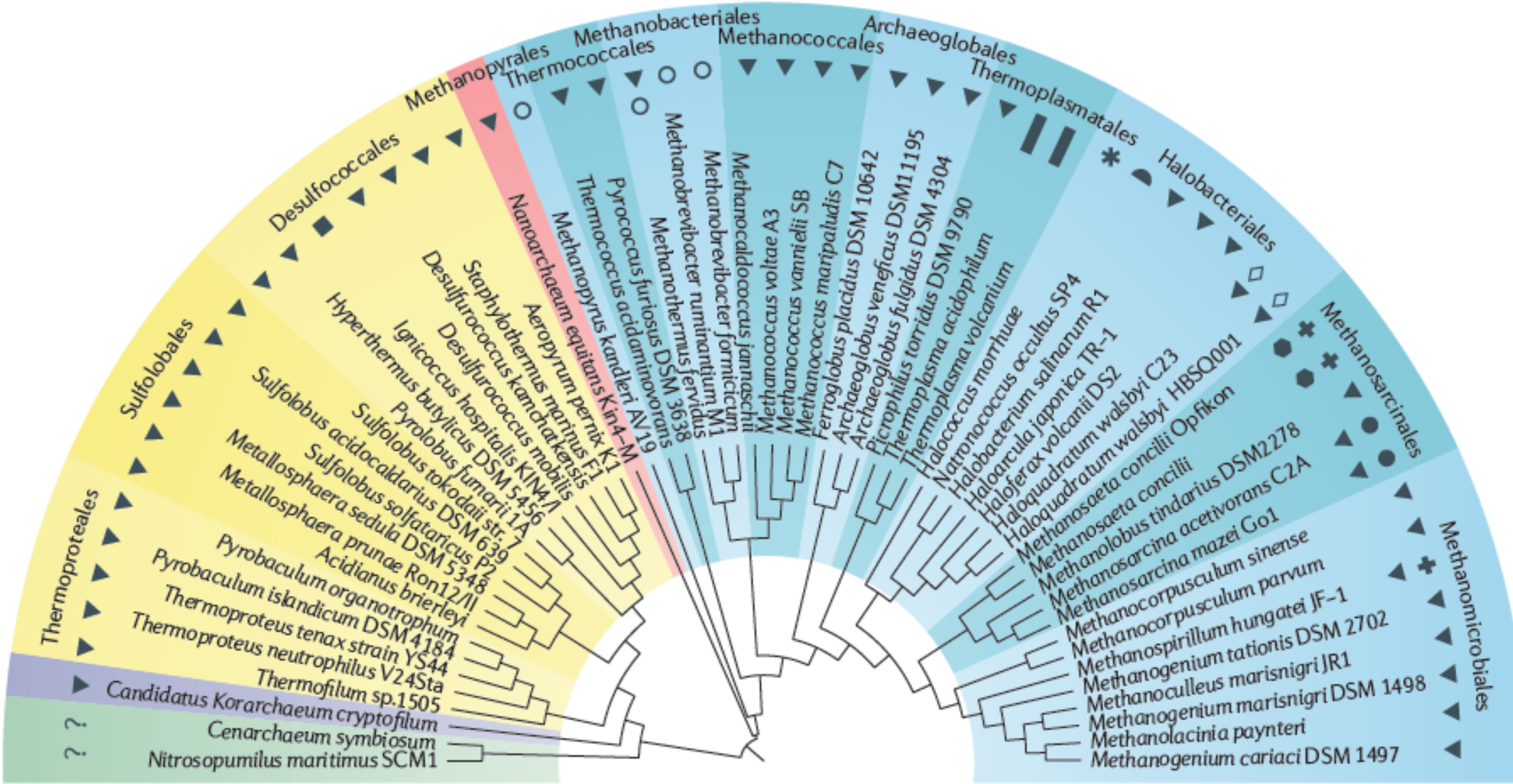
Williams TA, Foster PG, Cox CJ, Embley TM (2013) An archaeal origin of eukaryotes supports only two primary domains of life. *Nature* 504: 231-236

Also,

Asgard Archaea (include the Lokiarchaeota) = Archaea that branch near Eukarya and have Eukarya-like actin & profilin filaments (based on metagenomics)

Spang A et al. (2015) Complex archaea that bridge the gap between prokaryotes and eukaryotes. *Nature* 521:173–179
Akıl C & Robinson RC (2018) Genomes of Asgard archaea encode profilins that regulate actin *Nature* 562: 439–443

An ever-expanding archaeal tree

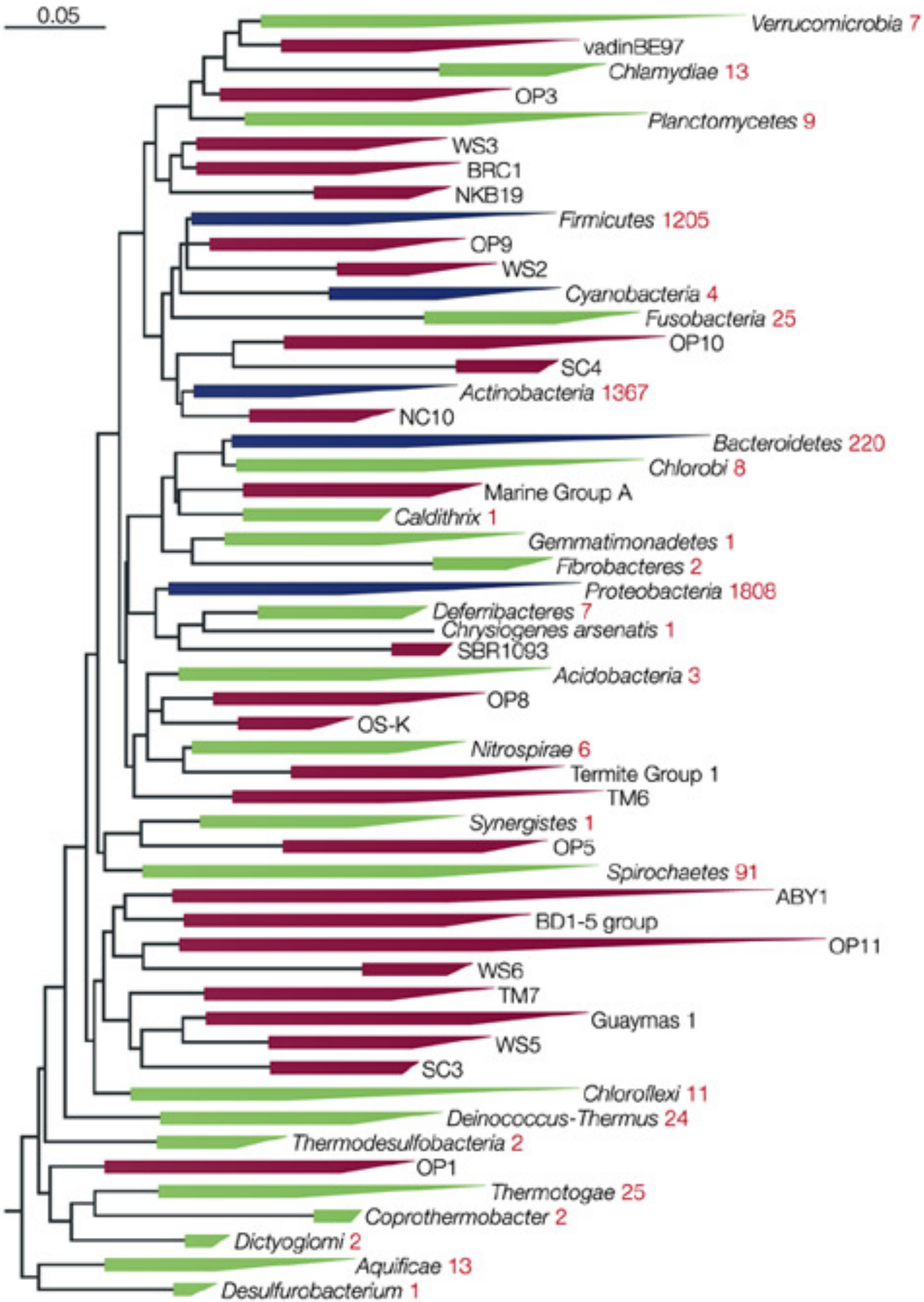


Major phyla of Archaea

- Thaumarchaeota
- Korarchaeota
- Crenarchaeota
- Nanoarchaeota
- Euryarchaeota

- ? Not analysed so far
- ▼ S-layer protein
- ■ Second membrane
- ○ Pseudomurein
- ▌ Glycocalyx (polysaccharide)
- ✱ Sulphated heteropolysaccharide
- ◓ Glutaminylglycan
- ◇ Halomucin
- ✚ Proteinaceous sheaths
- ⬢ Unspecified protein
- ● Methanochondroitin

Albers SV, Meyer BH (2011) The archaeal cell envelope. *Nature Reviews Microbiology* 9: 414-426



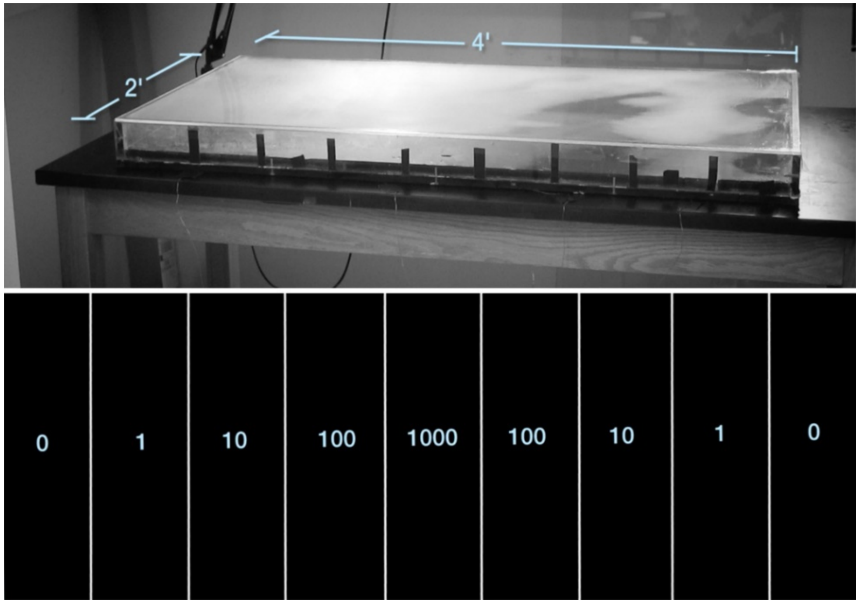
Phylogenetic tree of the domain Bacteria based on 16S rRNA gene sequences

(Keller, M. & Zengler, K. (2004) Tapping into microbial diversity. *Nature Reviews Microbiology.* **2:** 141-150)

Those phylogenetic groups with no cultivated representatives are shown in red (26/53)

Those with few cultivated representatives are in green

Rapid Evolution



E. coli evolves resistance to antibiotics in 11 days https://youtu.be/QUfyq8KMzyc

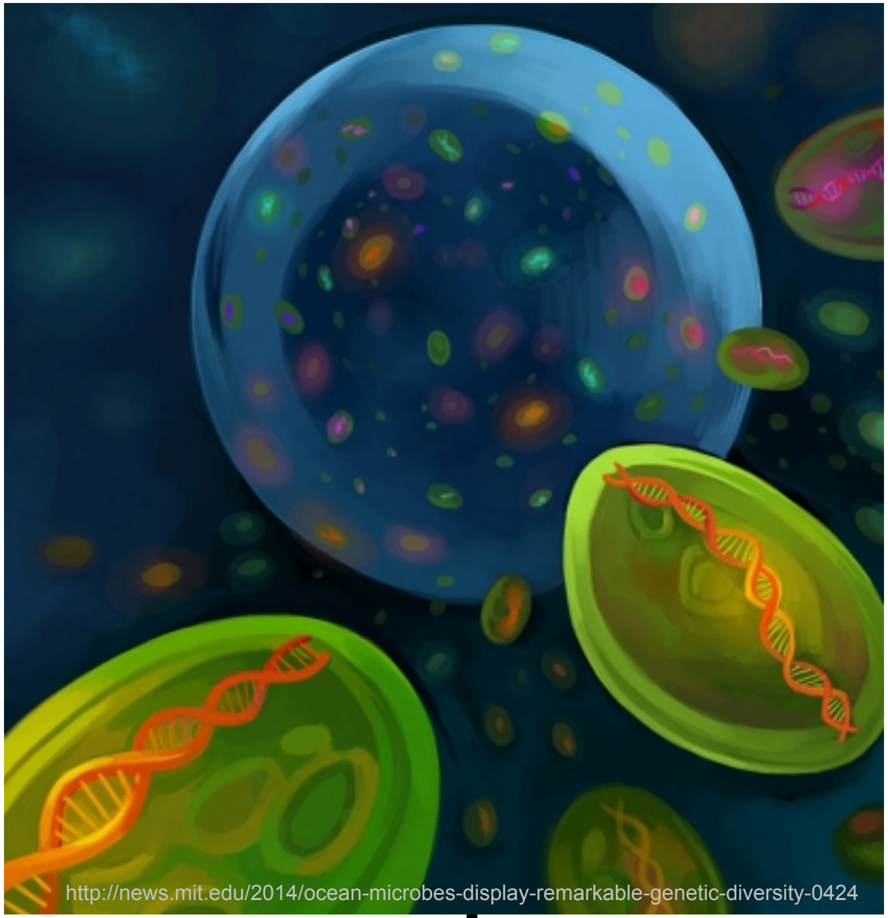
Baym M et al. (2016) Spatiotemporal microbial evolution on antibiotic landscapes. *Science* **53**: 1147-1151

Slow Evolution

Deep subsurface microbes

Karen Lloyd TED Talk
https://www.ted.com/talks/karen_lloyd_the_mysterious_microbes_living_deep_inside_the_earth_and_how_they_could_help_humanity/transcript?language=en

Massive **genetic diversity** in a drop of water or crumb of soil



Massive **metabolic diversity**

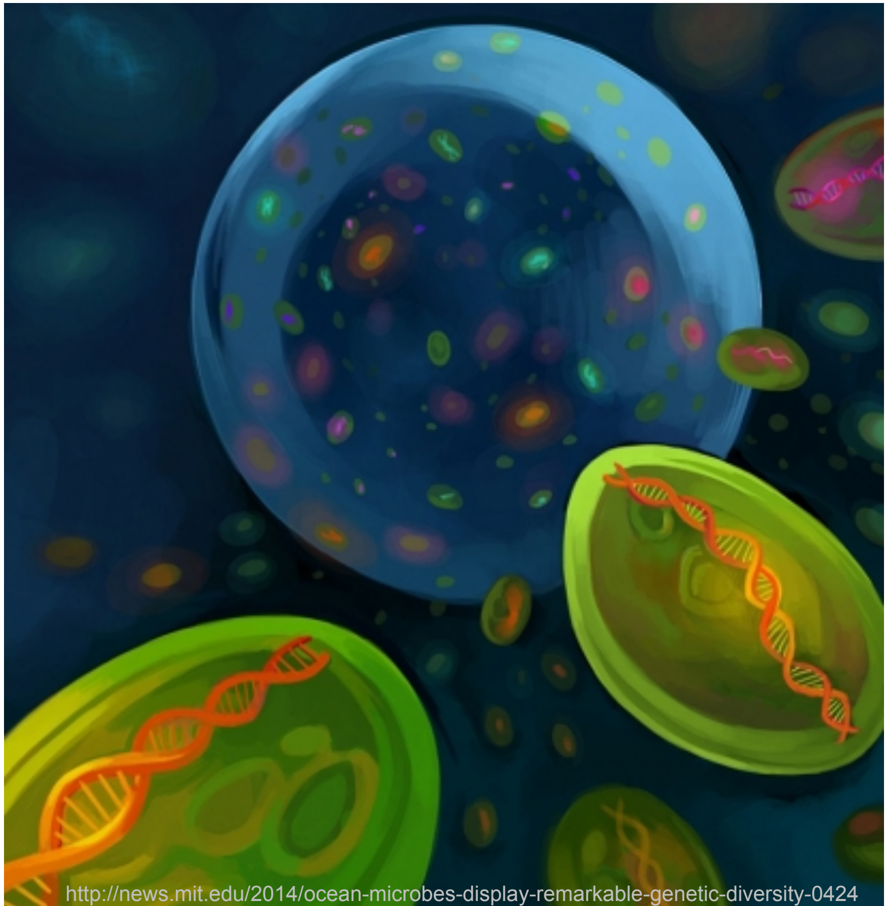
- Alter / control the chemistry of the Earth and its atmosphere

O_2, CO_2, methane,

But also

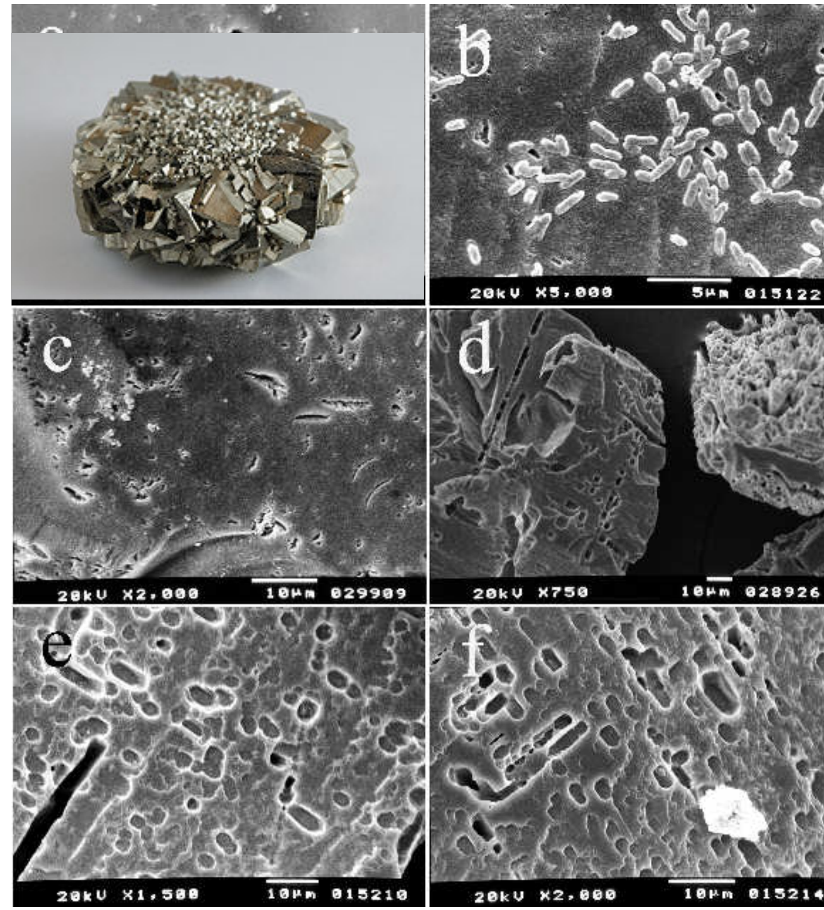
dimethylsulfide, isoprene, halogenated hydrocarbons etc.

Massive **genetic diversity** in a drop of water or crumb of soil



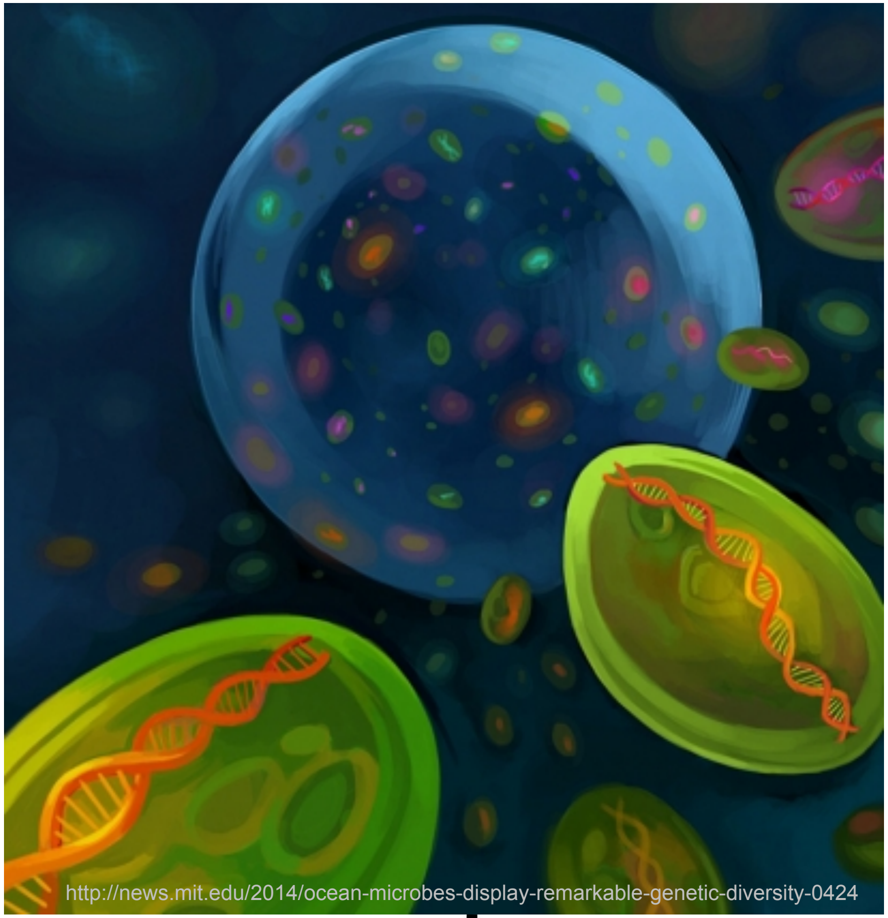
Massive **metabolic diversity**

- Alter / control the chemistry of the Earth and its atmosphere
- Make & break rocks



Microbial oxidation of pyrite by *Acidithiobacillus ferrooxidans*

Massive **genetic diversity** in a drop of water or crumb of soil

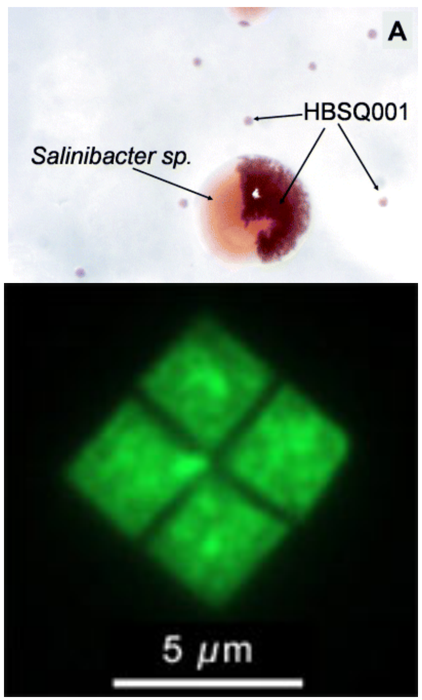


Massive **metabolic diversity**

- Alter / control the chemistry of the Earth and its atmosphere
- Make & break rocks
- Form & alter fossil fuels
- Central to global sustainable development
- Constantly evolving
- Compete and cooperate (think in terms of microbial communities)

McGenity TJ (2018) 2038 – When microbes rule the Earth. Environ Microbiol 20: 4213-4220

- What are microbes & how were/are they important for planet Earth?
- Genetic diversity
- **Metabolic diversity**
- Microbes in extremis
- Microbes in hypersaline environments & evaporites



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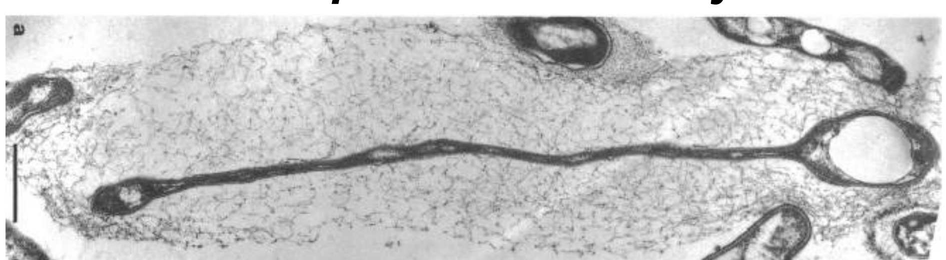

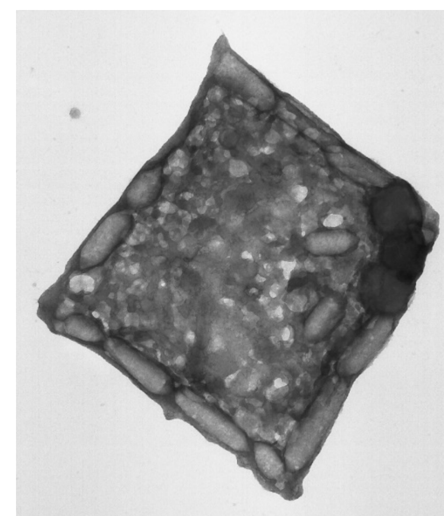

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Compositions as percentage of total number of atoms

universe		earth's crust		seawater		Living organisms
H	91	O	47	H	66	
He	9.1	Si	28	O	33	??
O	0.057	Al	7.9	Cl	0.33	
N	0.042	Fe	4.5	Na	0.28	
C	0.021	Ca	3.5	Mg	0.033	
Si	0.003	Na	2.5	S	0.017	
Ne	0.003	K	2.5	Ca	0.006	
Mg	0.002	Mg	2.2	K	0.006	
Fe	0.002	Ti	0.46	C	0.0014	
S	0.001	H	0.22	Br	0.0005	
		C	0.19			
Others <0.1		Others <0.1		Others <0.1		

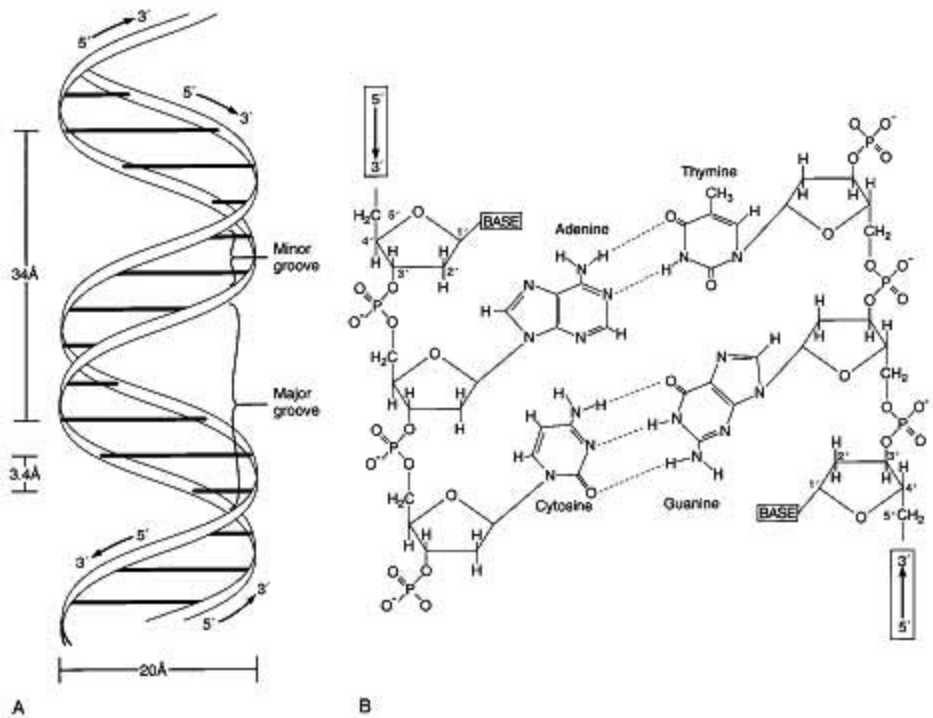
Frieden, E. (1972) The chemical elements of life. *Scientific American* **227:** 52

Compositions as percentage of total number of atoms

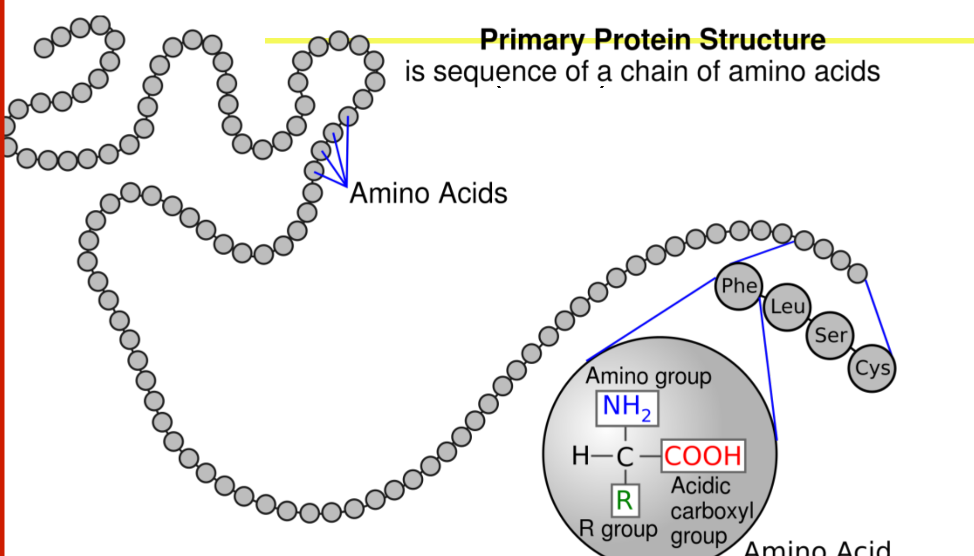
universe		earth's crust		seawater		human	
H	91	O	47	H	66	H	63
He	9.1	Si	28	O	33	O	25.5
O	0.057	Al	7.9	Cl	0.33	C	9.5
N	0.042	Fe	4.5	Na	0.28	N	1.4
C	0.021	Ca	3.5	Mg	0.033	Ca	0.31
Si	0.003	Na	2.5	S	0.017	P	0.22
Ne	0.003	K	2.5	Ca	0.006	Cl	0.03
Mg	0.002	Mg	2.2	K	0.006	K	0.06
Fe	0.002	Ti	0.46	C	0.0014	S	0.05
S	0.001	H	0.22	Br	0.0005	Na	0.03
		C	0.19			Mg	0.01
Others <0.1		Others <0.1		Others <0.1		Others <0.01	

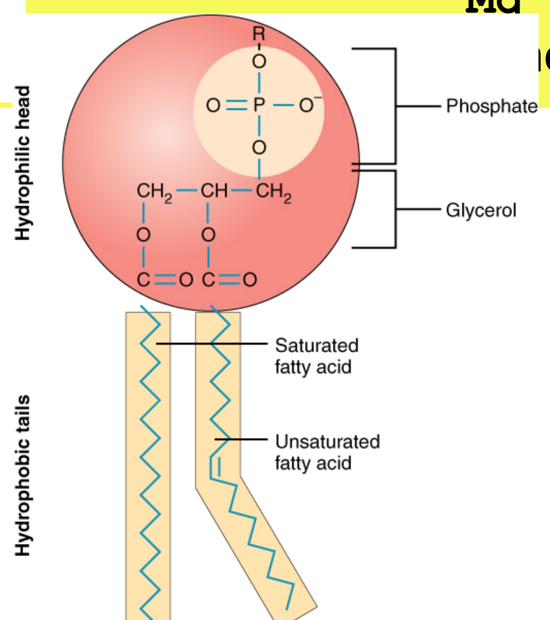
Frieden, E. (1972) The chemical elements of life. *Scientific American* **227:** 52

Compositions as percentage of total number of atoms

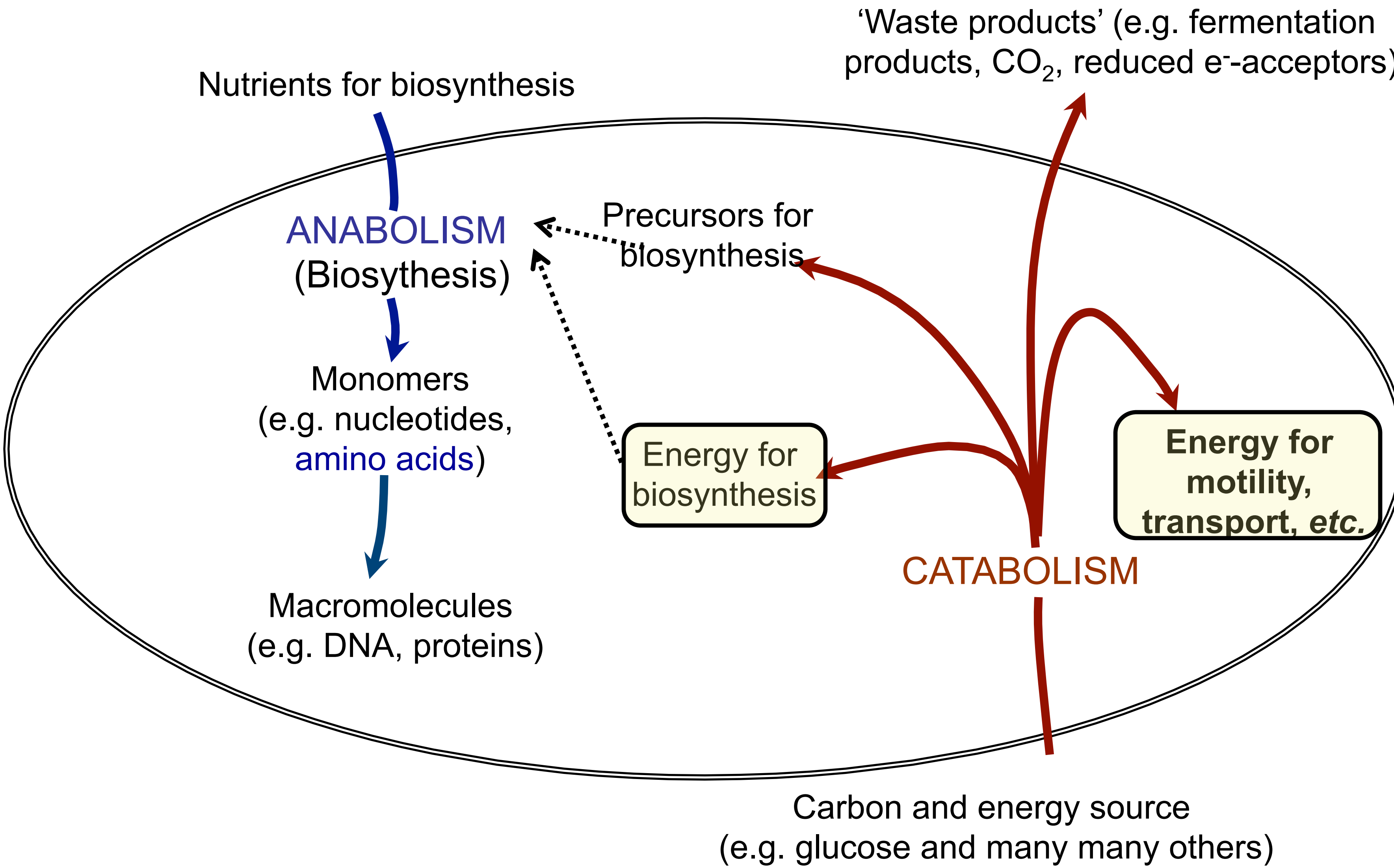


seawater		human	
H	66	H	63
O	33	O	25.5
Cl	0.33	C	9.5
Na	0.28	N	1.4
Mg	0.033	Ca	0.31
S	0.017	P	0.22
Ca	0.006	Cl	0.03
K	0.006	K	0.06
C	0.0014	S	0.05
Br	0.0005	Na	0.03
		Mg	0.01
		ers	<0.01





Cells need energy and building blocks to survive and grow



An encapsulation of metabolic diversity

Source of Carbon

Organic C [a]

CO_2 [b]

Source of Energy / Electron donor

Light + [c]

- H_2O [c1]
- H_2
- H_2S
- S°
- Fe^{2+}
- organic C

[c2]

Chemicals [d]

Inorganic [d1]	Organic [d2]
H_2	glucose
H_2S	amino acids
S°	acetate
NH_4^+	alkanes
Fe^{2+}	cellulose
Mn^{2+}	etc.

Terminal electron acceptor used

No [e]

Yes: [f]

- O_2 [f1]
- NO_3^-
- Mn^{4+}
- Fe^{3+}
- SO_4^{2-}
- CO_2

[f2]

---

[a] heterotroph
[b] autotroph

[c] phototroph
[c1] oxygenic phototroph
[c2] anoxygenic phototroph

[d] chemotroph
[d1] chemolithotroph
[d2] chemoorganotroph

[e] fermentation
[f] respiration
[f1] aerobic respiration
[f2] anaerobic respiration

Source of Carbon	Source of Energy / Electron donor			Terminal electron acceptor used
	Light + [c]	Chemicals [d]		
		Inorganic [d1]	Organic [d2]	
Organic C [a]	H_2O [c1]	H_2	glucose	No [e]
CO_2 [b]	H_2	H_2S	amino acids	Yes: [f]
	H_2S	S°	acetate	O_2 [f1]
	S°	NH_4^+	alkanes	NO_3^-
	Fe^{2+}	Fe^{2+}	cellulose	Mn^{4+}
	organic C	Mn^{2+}	etc.	Fe^{3+}
				SO_4^{2-}
				CO_2

[c2] (H_2, H_2S, S°, Fe^{2+}, organic C)

[f2] (NO_3^-, Mn^{4+}, Fe^{3+}, SO_4^{2-}, CO_2)

[a] heterotroph
[b] autotroph

[c] phototroph
[c1] oxygenic phototroph
[c2] anoxygenic phototroph

[d] chemotroph
[d1] chemolithotroph
[d2] chemoorganotroph

[e] fermentation
[f] respiration
[f1] aerobic respiration
[f2] anaerobic respiration

Example = humans; *E. coli*

Source of Carbon	Source of Energy / Electron donor			Terminal electron acceptor used
	Light + [c]	Chemicals [d]		
		Inorganic [d1]	Organic [d2]	
Organic C [a]	H_2O [c1]			No [e]
CO_2 [b]	H_2	H_2	glucose	Yes: [f]
	H_2S	H_2S	amino acids	O_2 [f1]
	S°	S°	acetate	NO_3^-
	Fe^{2+}	NH_4^+	alkanes	Mn^{4+}
	organic C	Fe^{2+}	cellulose	Fe^{3+}
	(H_2 … organic C: [c2])	Mn^{2+}	etc.	SO_4^{2-}
				CO_2
				(NO_3^- … CO_2: [f2])

[a] heterotroph
[b] autotroph

[c] phototroph
[c1] oxygenic phototroph
[c2] anoxygenic phototroph

[d] chemotroph
[d1] chemolithotroph
[d2] chemoorganotroph

[e] fermentation
[f] respiration
[f1] aerobic respiration
[f2] anaerobic respiration

Example = *E. coli*

Source of Carbon

Organic C [a]

$\boxed{CO_2}$ [b]

Source of Energy / Electron donor

Light + [c]

H_2O [c1]

H_2
H_2S
S°
Fe^{2+}
organic C

[c2]

Chemicals [d]

Inorganic [d1]	Organic [d2]
H_2	glucose
$\boxed{H_2S}$	amino acids
S°	acetate
NH_4^+	alkanes
Fe^{2+}	cellulose
Mn^{2+}	etc.

Terminal electron acceptor used

No [e]

$\boxed{\text{Yes:}}$ [f]

O_2 [f1]

$\boxed{NO_3^-}$
Mn^{4+}
Fe^{3+}
SO_4^{2-}
CO_2

[f2]

[a] heterotroph
[b] autotroph

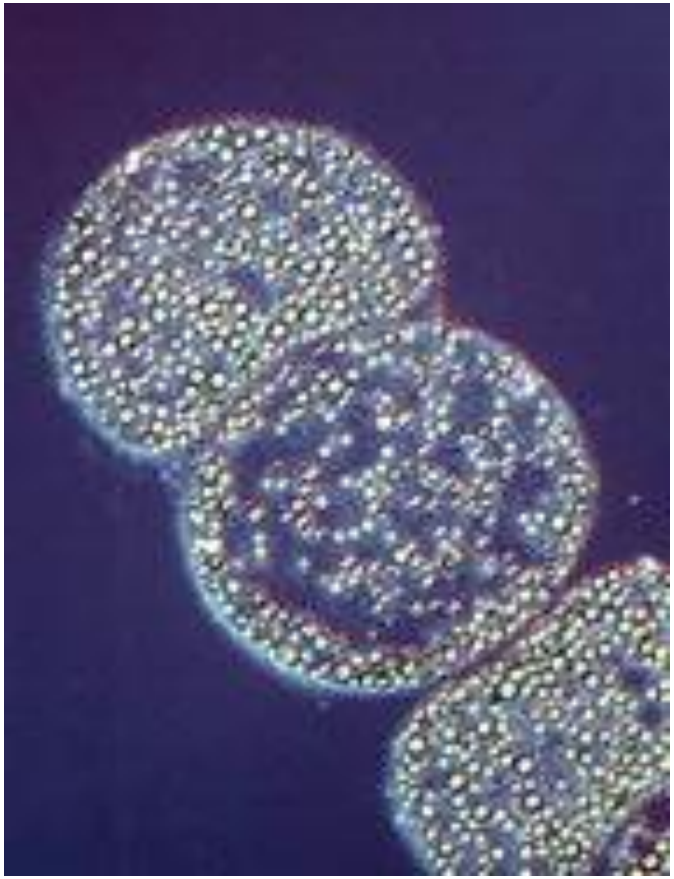
[c] phototroph
[c1] oxygenic phototroph
[c2] anoxygenic phototroph

[d] chemotroph
[d1] chemolithotroph
[d2] chemoorganotroph

[e] fermentation
[f] respiration
[f1] aerobic respiration
[f2] anaerobic respiration

Example = *Thiomargarita namibiensis* (a type of anaerobic chemolithoautotroph, *but* new evidence hints at mixotrophy, and aerobic respiration!)

Sediment core from the Benguela upwelling (courtesy Nat Hicks)



Thiomargarita namibiensis
diameter = 400 μm

Schulz HN et al. (1999) Dense populations of a giant sulfur bacterium in Namibian shelf sediments. *Science* **284:** 493-495

Source of Carbon

$\boxed{\text{Organic C}}$ [a]

CO_2 [b]

Source of Energy / Electron donor

Light + [c]

H_2O [c1]

H_2
H_2S
S°
Fe^{2+}
organic C
} [c2]

Chemicals [d]

Inorganic [d1]	Organic [d2]
H_2	glucose
H_2S	amino acids
S°	$\boxed{\text{acetate}}$
NH_4^+	alkanes
Fe^{2+}	cellulose
Mn^{2+}	etc.

Terminal electron acceptor used

No [e]

$\boxed{\text{Yes:}}$ [f]

O_2 [f1]

NO_3^-
$\boxed{Mn^{4+}}$
$\boxed{Fe^{3+}}$
SO_4^{2-}
CO_2
} [f2]

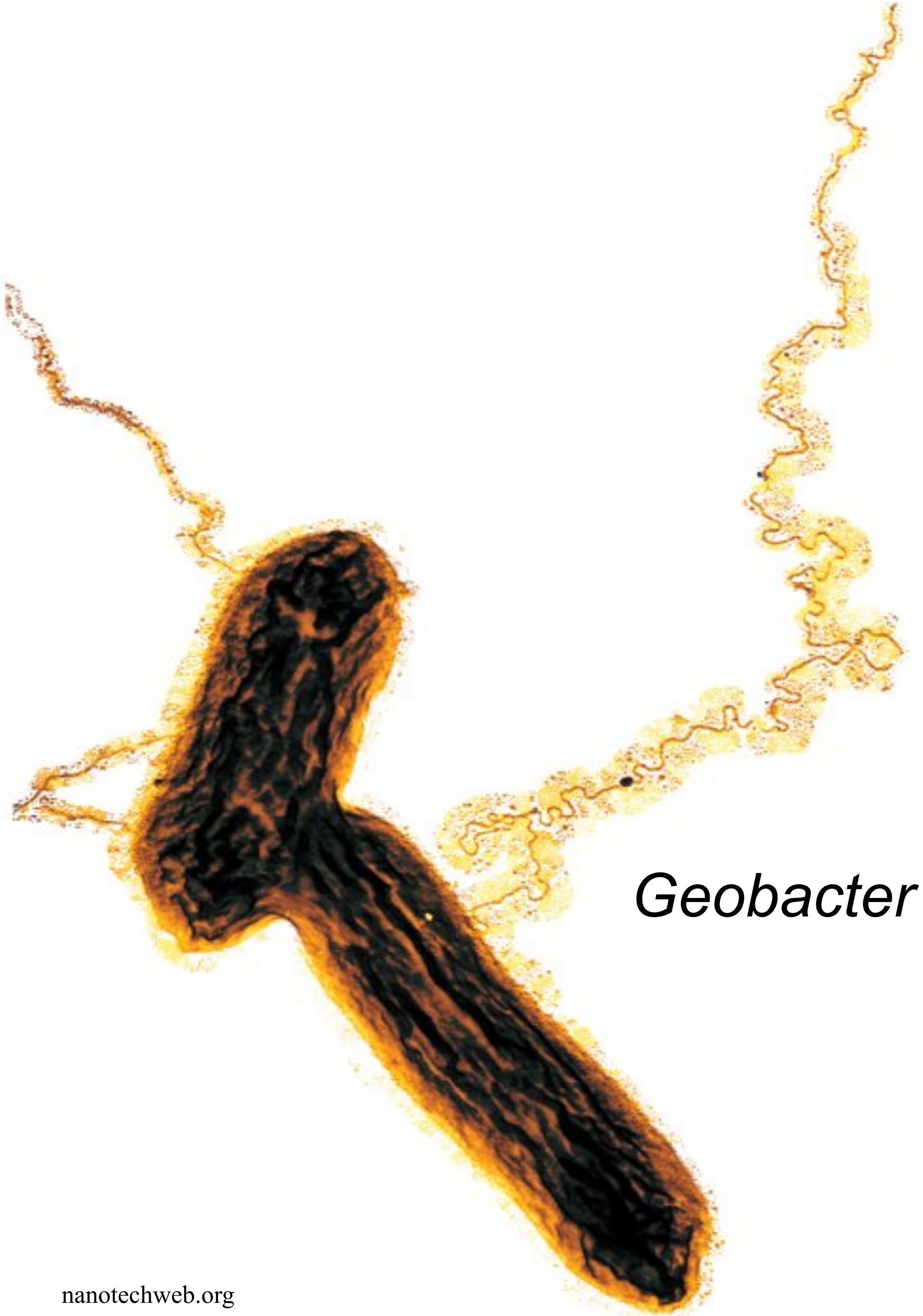
[a] heterotroph
[b] autotroph

[c] phototroph
[c1] oxygenic phototroph
[c2] anoxygenic phototroph

[d] chemotroph
[d1] chemolithotroph
[d2] chemoorganotroph

[e] fermentation
[f] respiration
[f1] aerobic respiration
[f2] anaerobic respiration

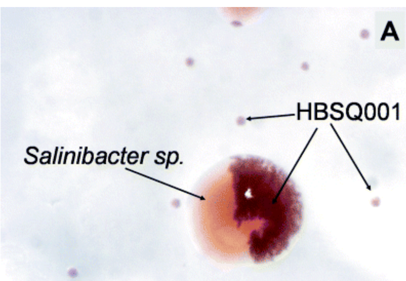
Example = *Geobacter metallireducens*

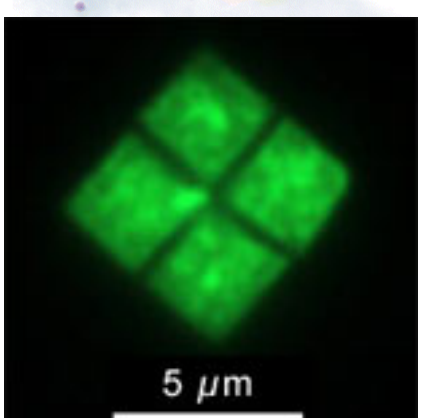


Geobacter sp. shuttle electrons

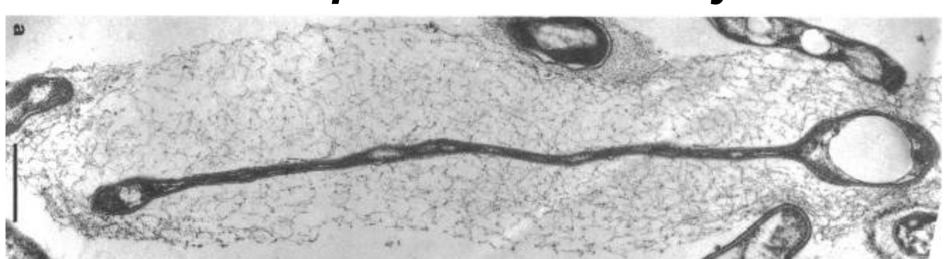
nanotechweb.org

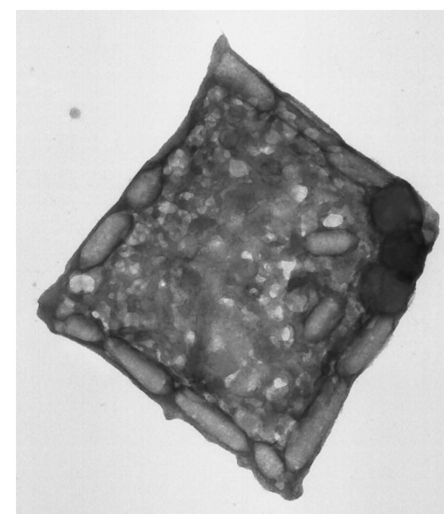
- What are microbes & how were/are they important for planet Earth?
- Genetic diversity
- Metabolic diversity
- **Microbes in extremis**
- Microbes in hypersaline environments & evaporites





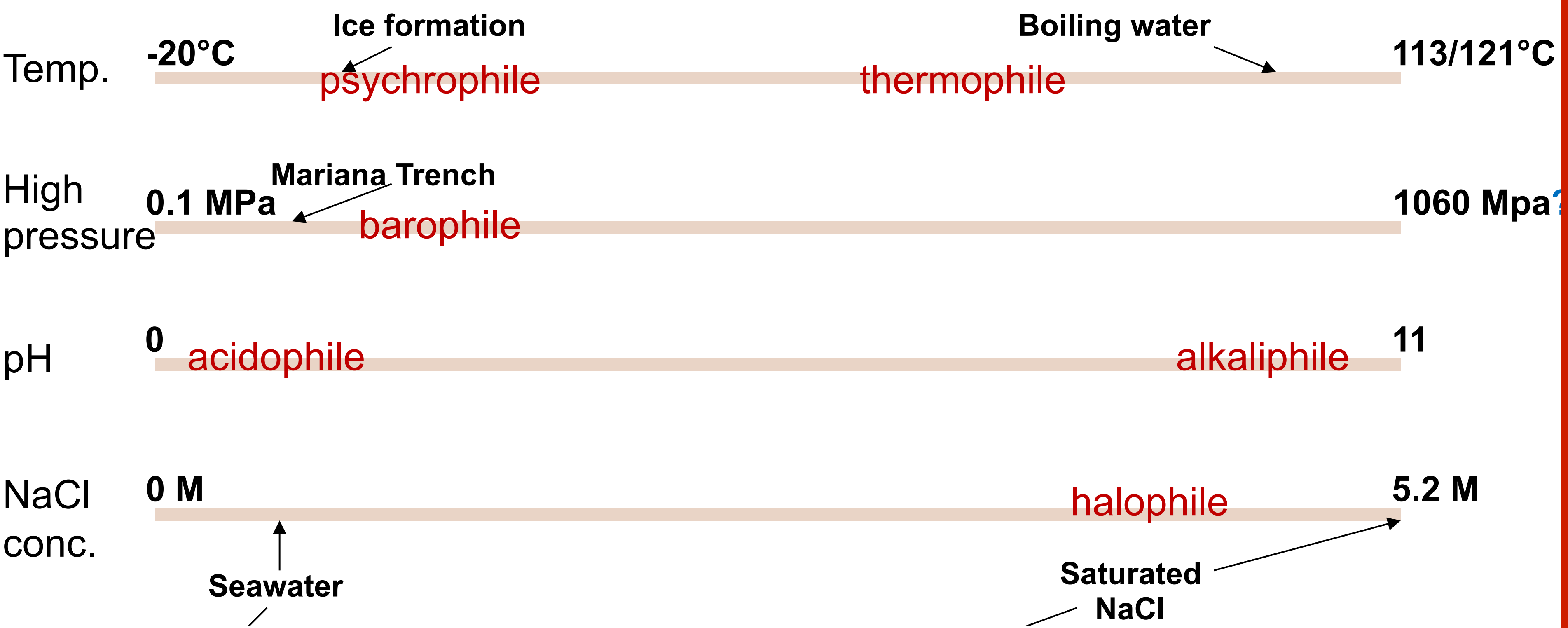
Haloquadratum walsbyi





Bolhuis H *et al.* (2004) *Environ Microbiol* 6: 1287-1291. Kessel M, Cohen Y (1982) *J Bact* **150:** 851-860

Proposed windows of life for selected parameters



- **Survival *v* growth**
- **Pure culture *v in-situ* activity**
- **Degrees of uncertainty over methods at extremes**

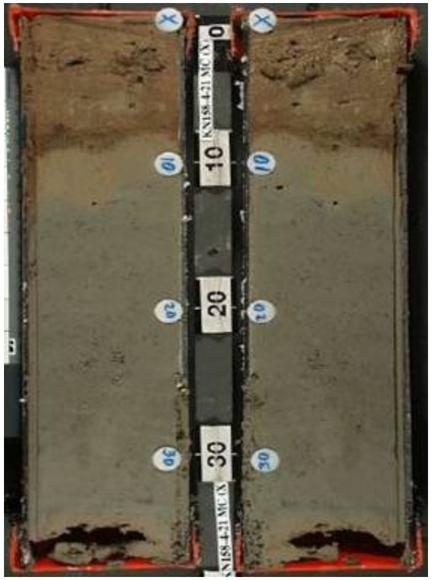
Deep biosphere

•Microbes present and "just about active" in deep-sea sediments

•Record = 2458 mbs in lignite beds – Inagaki et al. (2015) Science 349: 420-424

• Energy from, e.g. H_2, necromass; occasionally hydrocarbons

•Terminal electron acceptors (next slide)



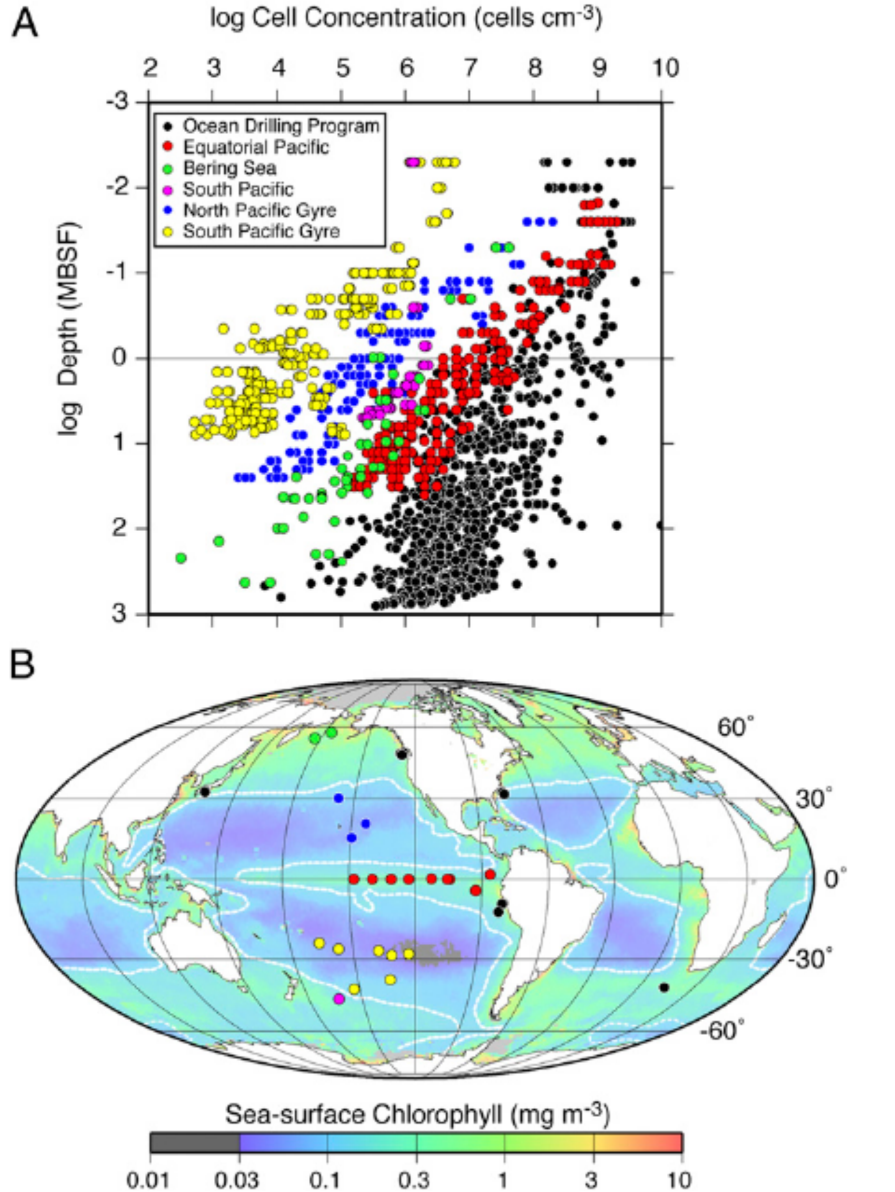
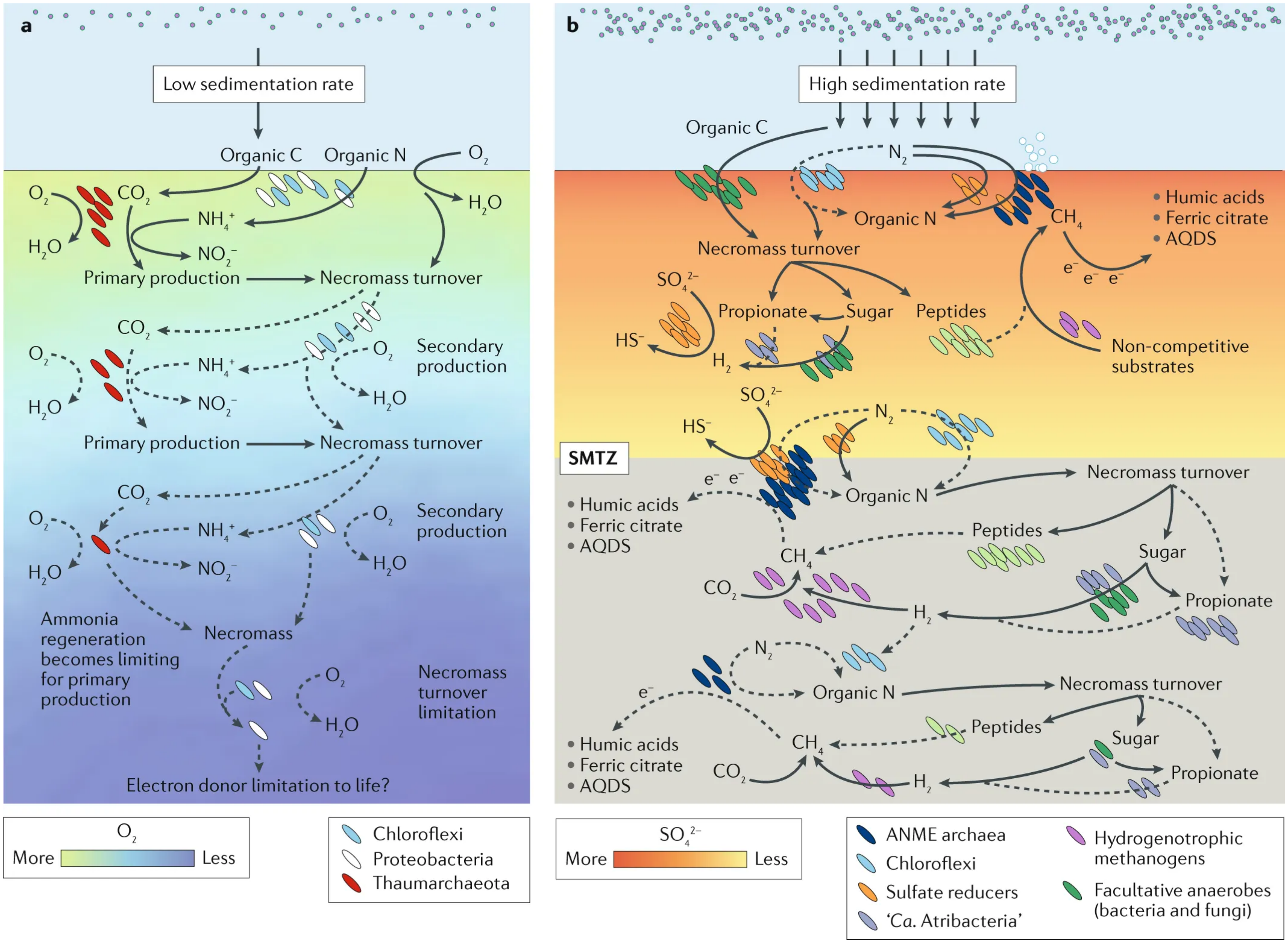


Fig. 1. Subseafloor sedimentary cell counts used for this study. (*A*) Counted cell concentration vs. depth (mbsf) for the sites used in this study. (*B*) Site locations overlain on a map of time-averaged sea surface chlorophyll-a (34).

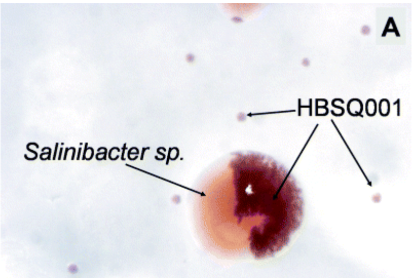
Kallmeyer (2012) Global distribution of microbial abundance and biomass in subseafloor sediment. *PNAS* 109:16213-16216

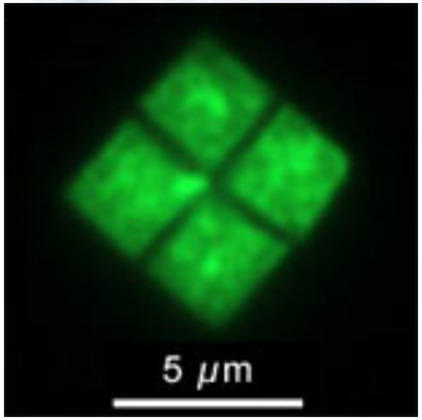
Microbial element cycling in deep subsurface sediments



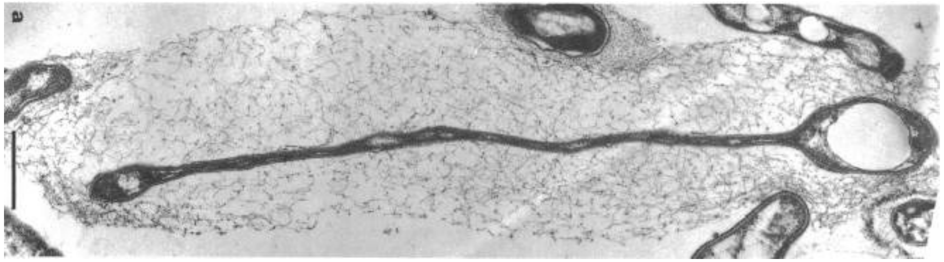
Orsi WD (2018) Ecology and evolution of seafloor and subseafloor microbial communities. Nat Rev Microbiol 16: 671–683

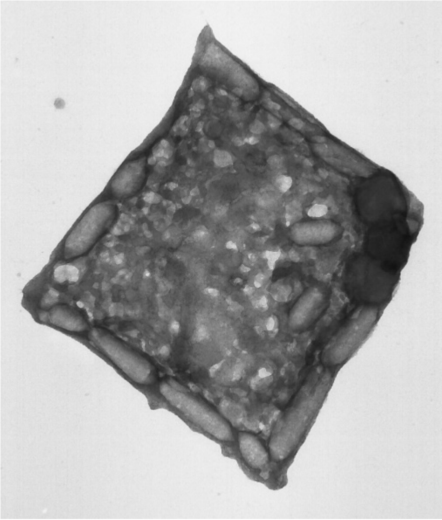
- What are microbes & how were/are they important for planet Earth?
- Genetic diversity
- Metabolic diversity
- Microbes in extremis
- **Microbes in hypersaline environments & evaporites**





Haloquadratum walsbyi





Bolhuis H *et al.* (2004) *Environ Microbiol* 6: 1287-1291. Kessel M, Cohen Y (1982) *J Bact* **150:** 851-860

Proposed windows of life for selected parameters

NaCl conc. 0 M — 5.2 M

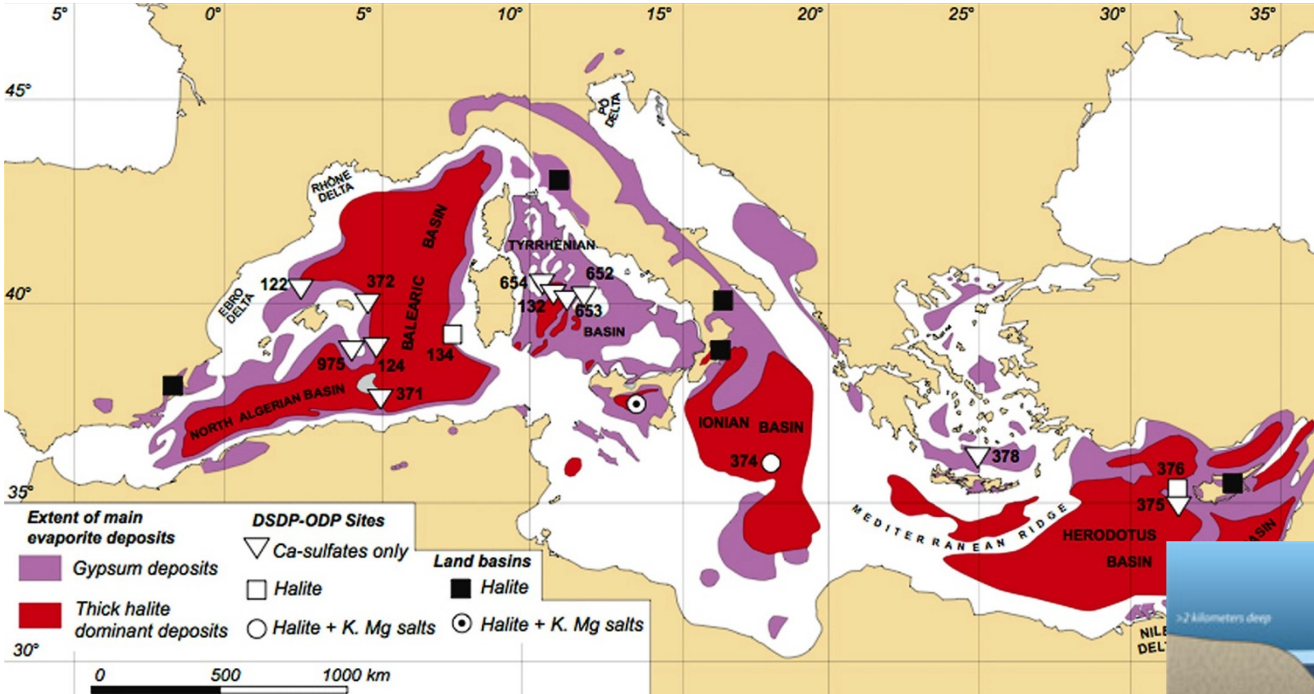
Seawater

Saturated NaCl

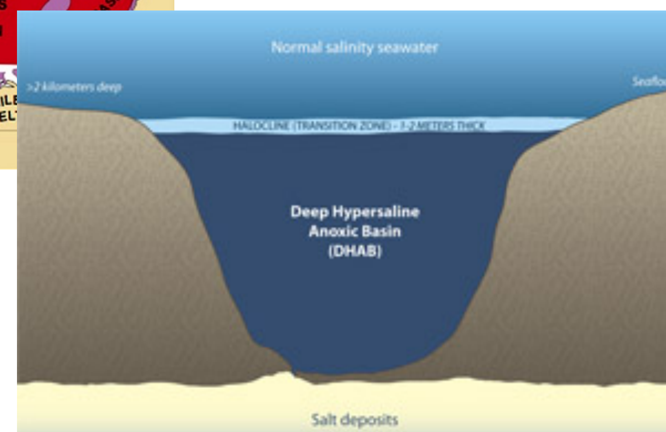
Honey

a_w 1 — 0.605

Diversity of hypersaline environments



Thick **halite** deposits beneath the Mediterranean http://www.ciesm.org



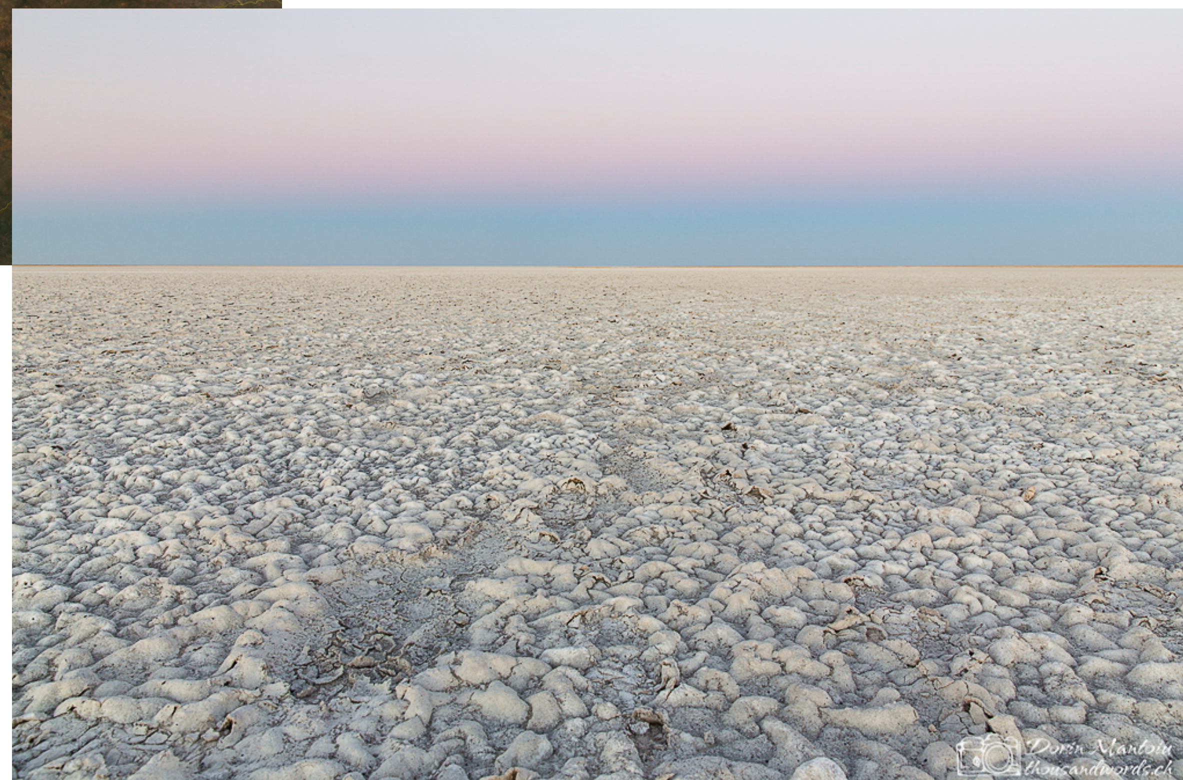
Deep-sea hypersaline anoxic brine lakes

Salt glaciers in the Zagros Mountains, Iran (NASA)

Diversity of hypersaline environments

Makgadikadi salt pan, Botswana

(NASA; http://thousandwords.ch)

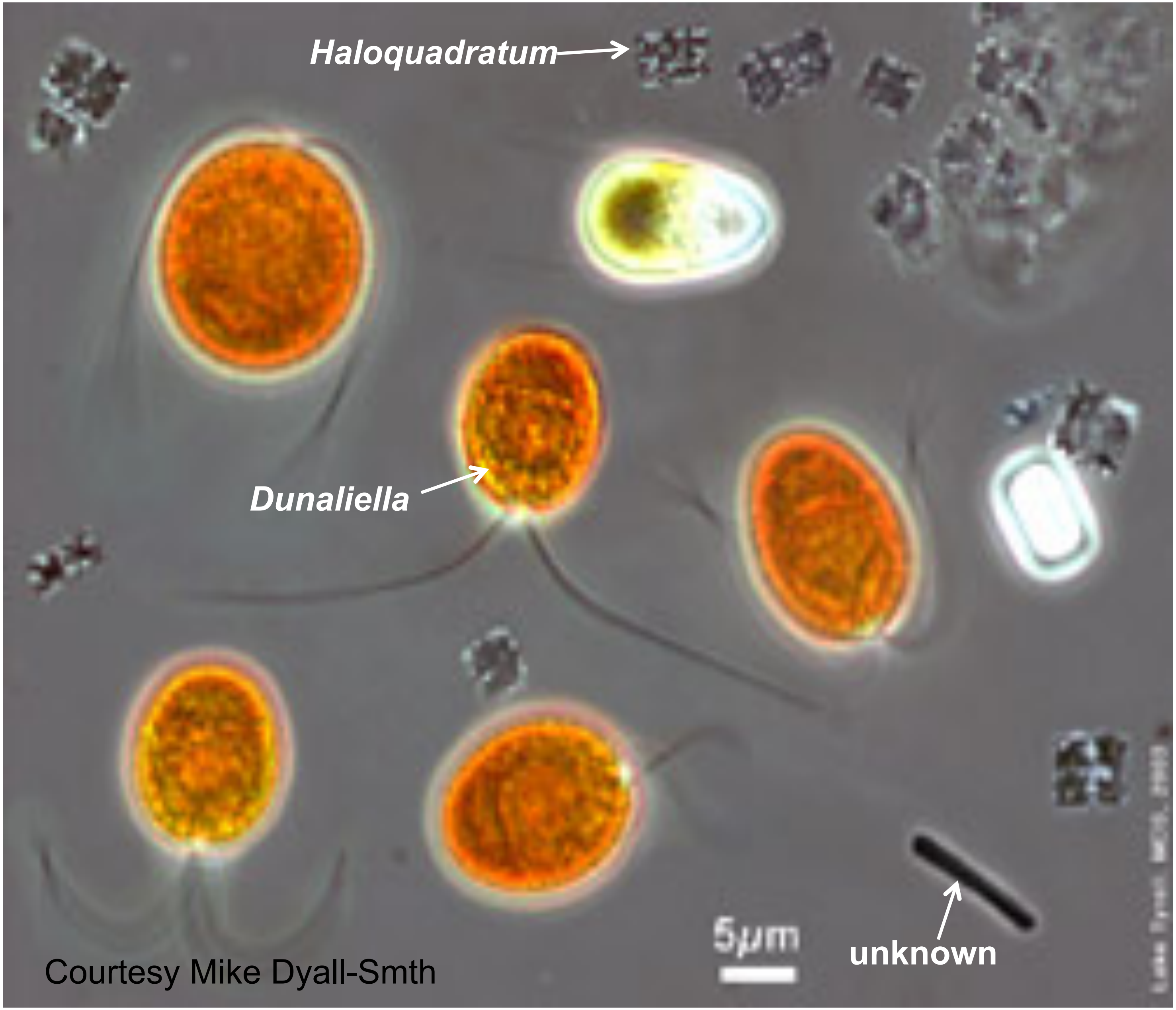


Hypersaline brines are (and would have been in the past) dominated by Archaea, Bacteria and a select few Eukarya

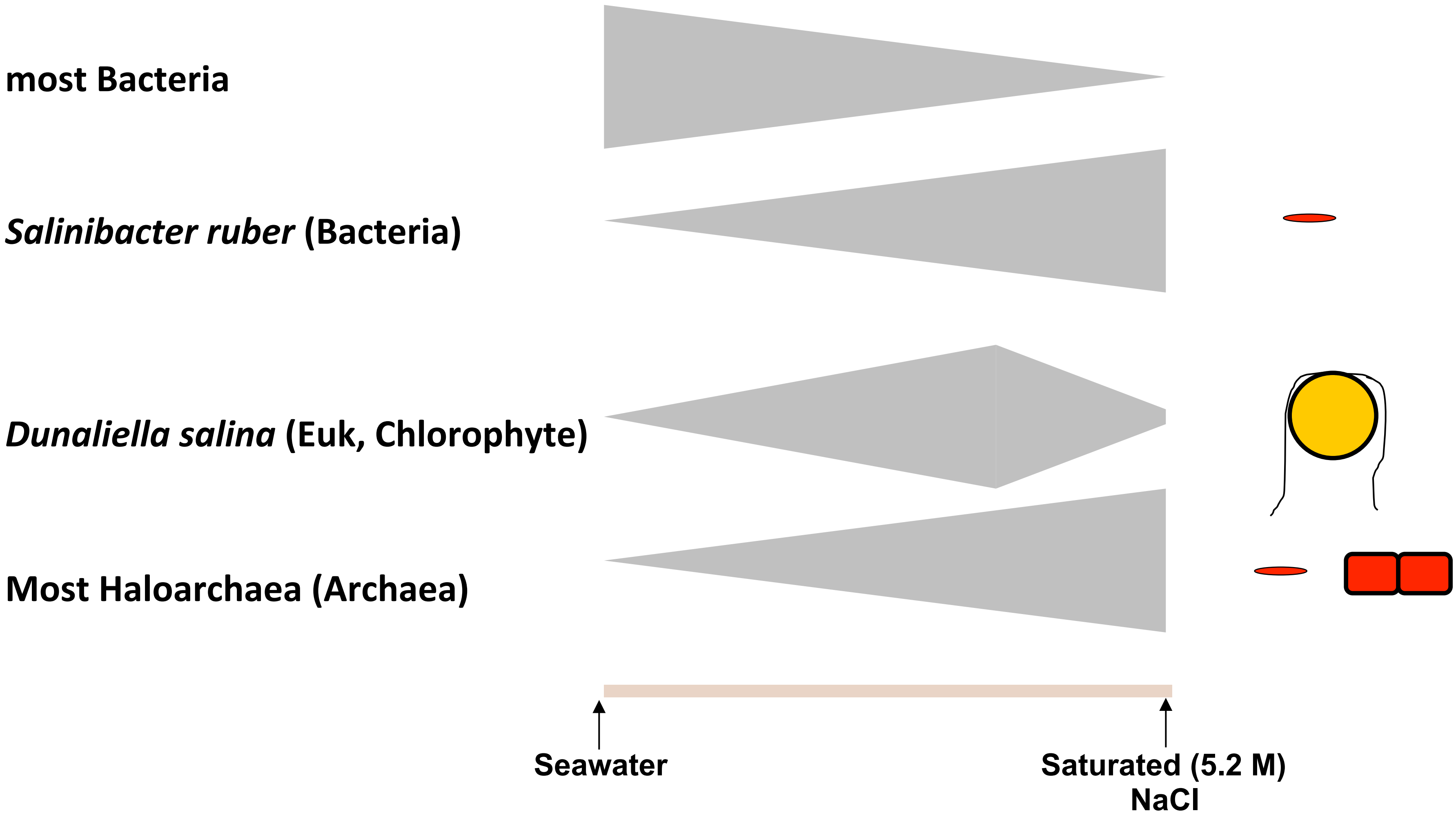
San Francisco Bay salterns (NASA)

Gypsum crust from the bottom of a shallow saltern pond (200 g l^{-1} salinity) in Eilat, Israel, showing layered communities of phototrophic microbes.

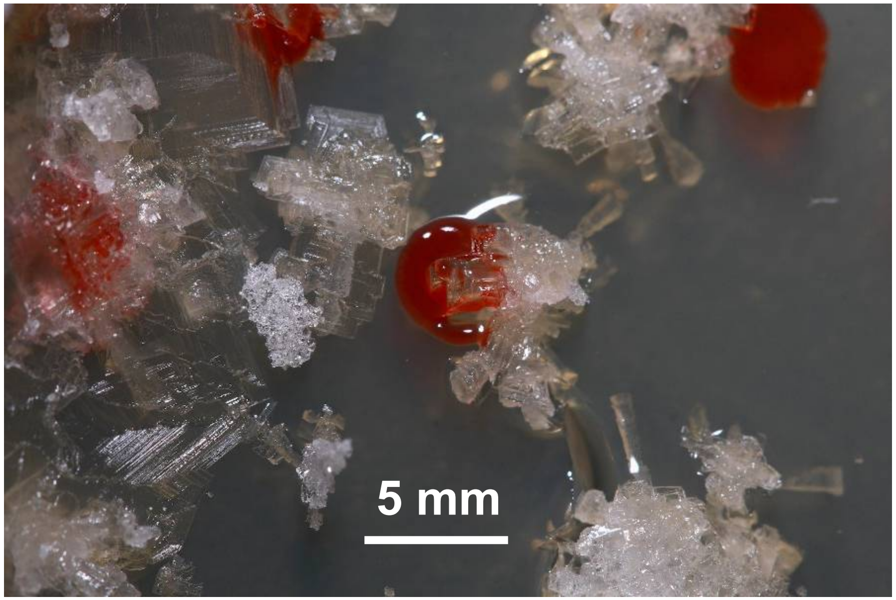
Courtesy Andreas Thywißen.


Haloquadratum
Dunaliella
5μm
unknown
Courtesy Mike Dyall-Smth

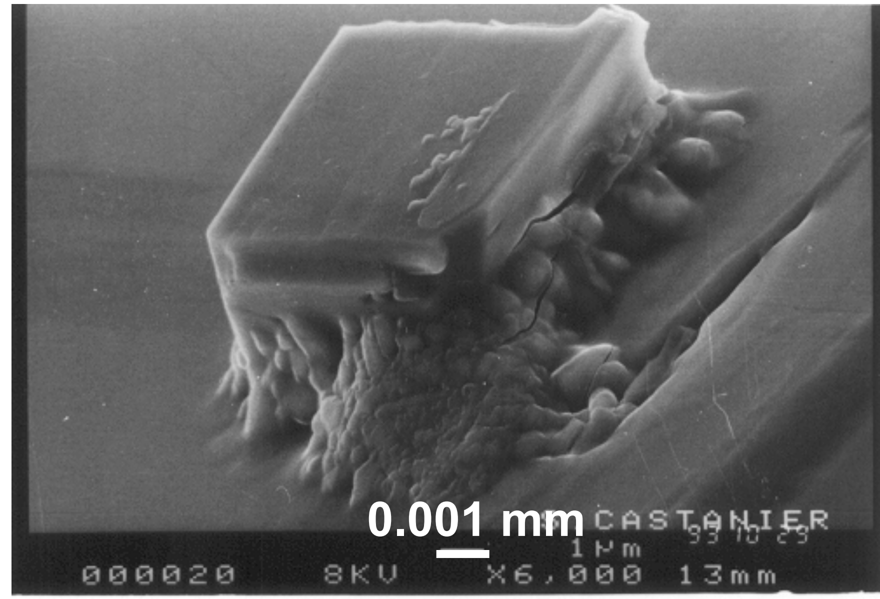
Schematic of change in abundance in the water column of a solar saltern with increasing salinity



Haloarchaea become trapped inside halite

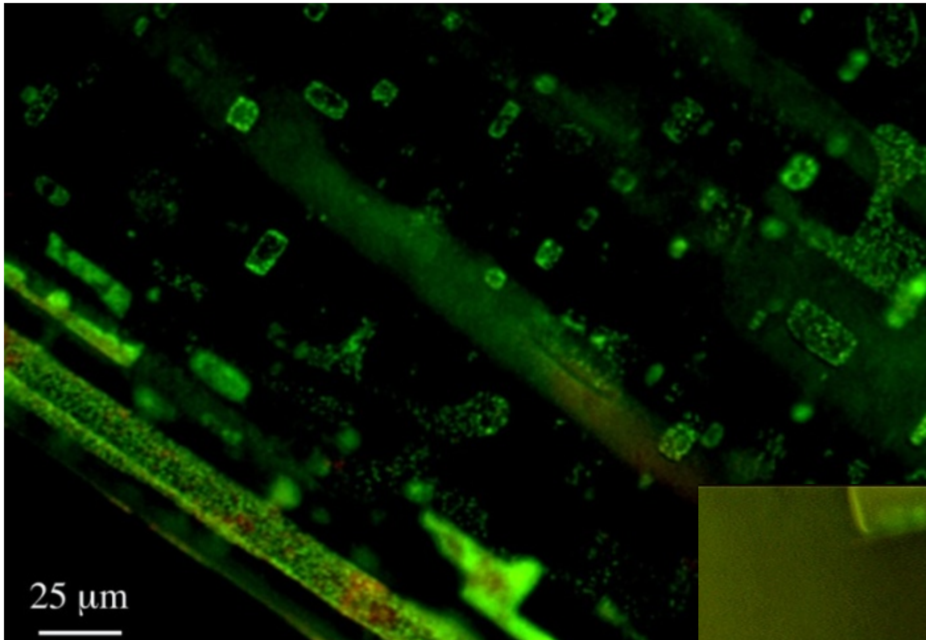


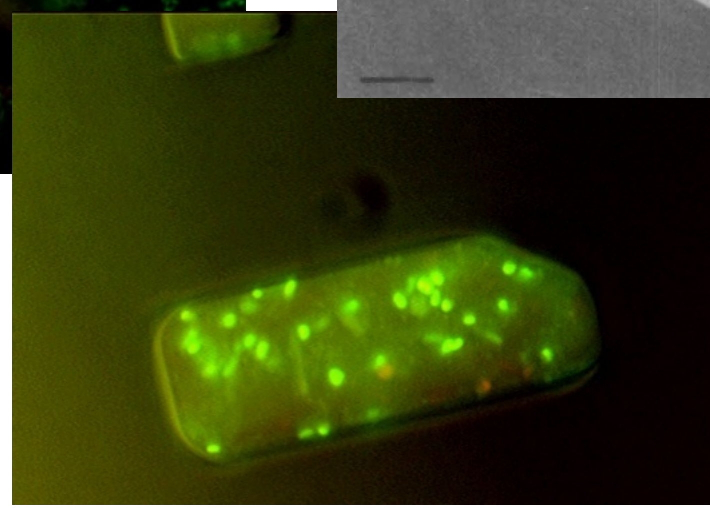
Halobacterium NRC-1 growing around / on salt crystals on a dried-out plate Courtesy Matt W. Ford. www.pandasthumb.org

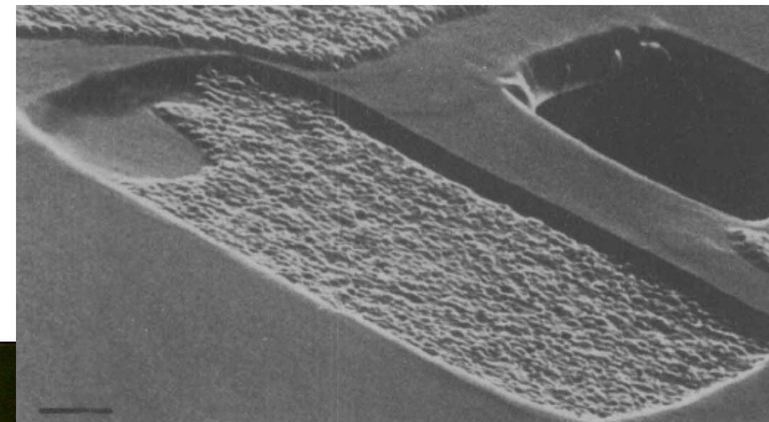


Halite crystal forming around microbial cells in the Berre salt works Courtesy Sabine Castanier

& live inside brine inclusions

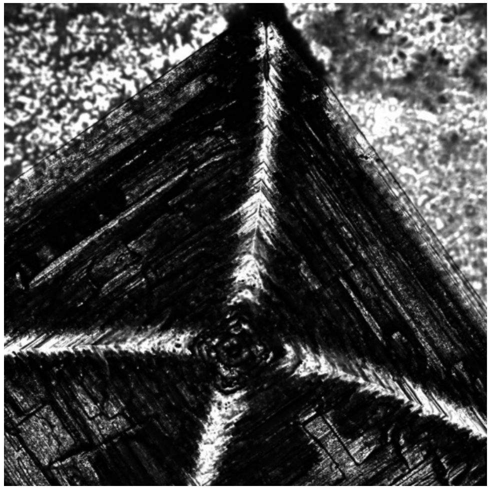


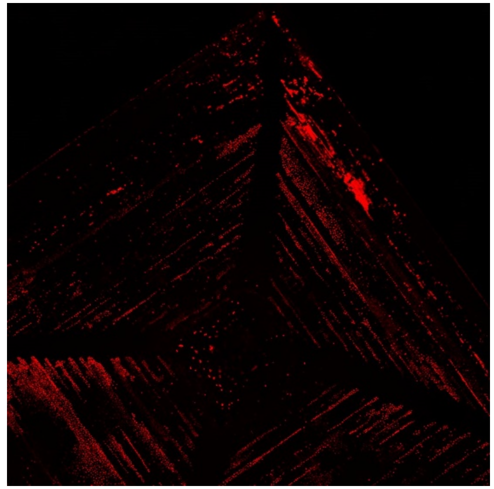




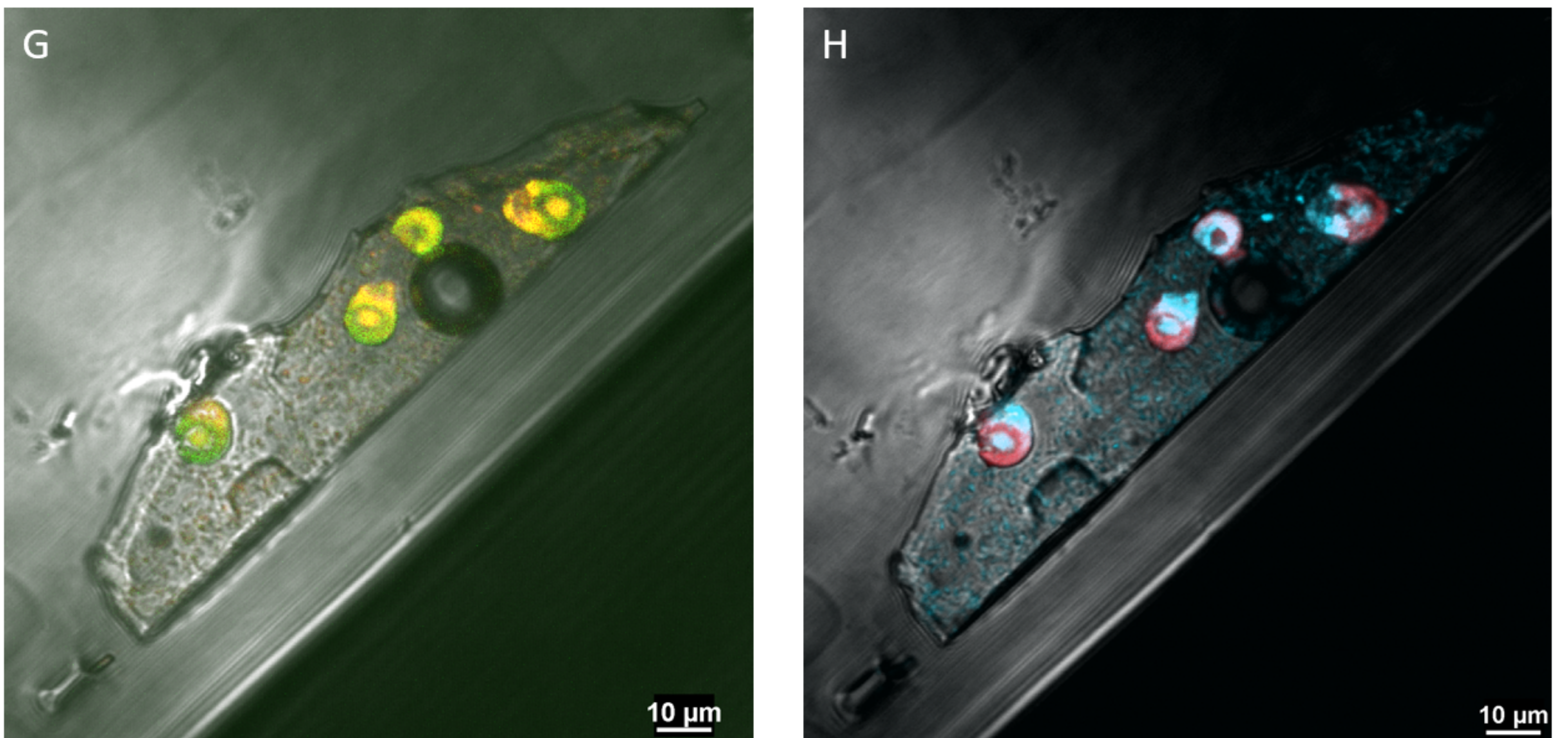
Norton & Grant (1988) J Gen Microbiol 134: 1365-1373
Dombrowski (1966) In 2nd Symposium on Salt Vol 1, Rau JL (ed). Northern Ohio Geological Society
Fendrihan et al. (2009) Astrobiology 9: 104-112

Also with *Dunaliella salina*



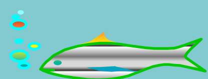


Thanks to
Nora Georgiev,
Maria Magliuo &
Philippe Laissue



to avoid desiccation and the increasingly chaotropic Mg-rich brine that is left behind

seawater



	g/kg
Na	**10.56**
Mg	**1.27**
Ca	**0.40**
K	**0.38**
Sr	**0.01**
Cl	**18.98**
SO_4	**2.65**
HCO_3	**0.14**
Br	**0.06**
H_3BO_3	**0.03**

$CaCO_3$
carbonate
minerals

50%

$CaSO_4.2H_2O$
gypsum

80-90%

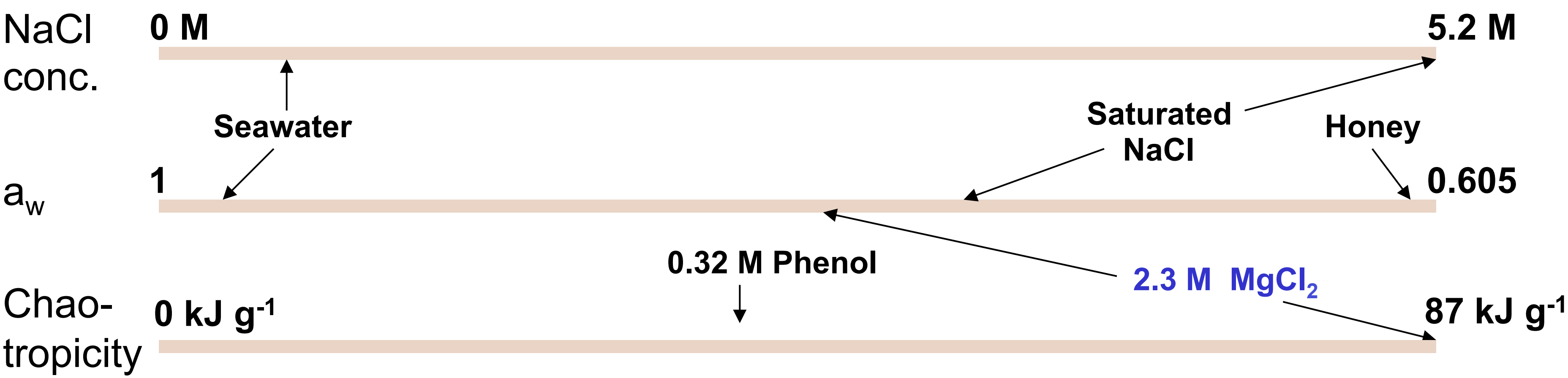
NaCl
halite

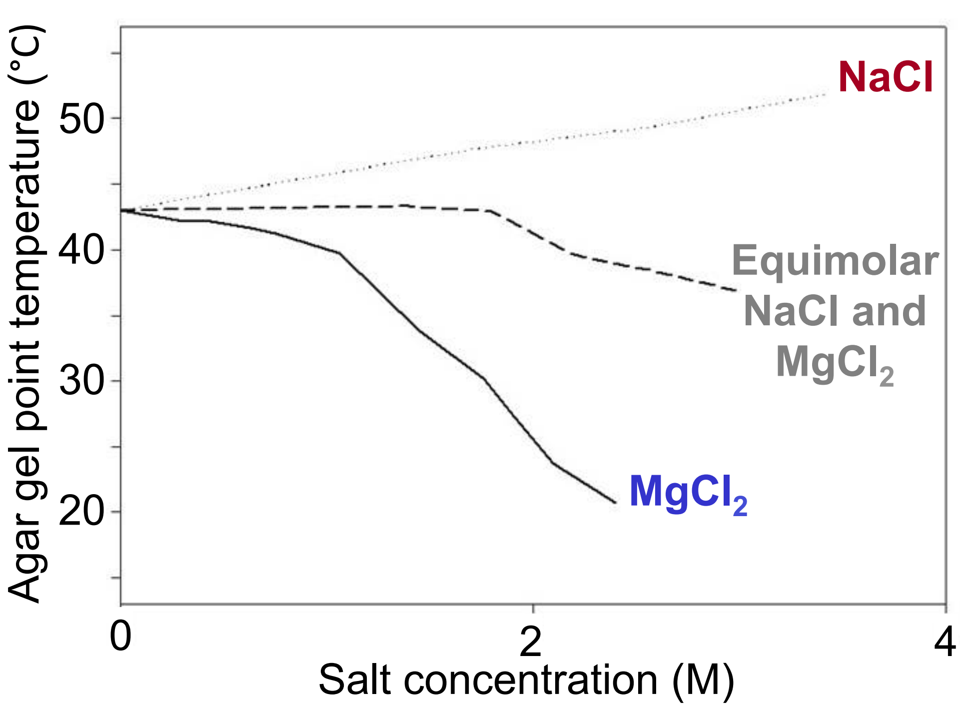
86-94%

Remaining brine has a high conc-entration of Mg^{2+}

Percentage evaporation giving rise to different minerals

Proposed windows of life for selected parameters

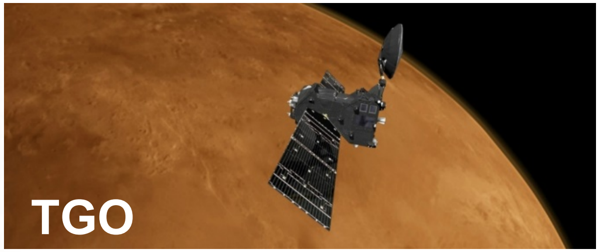




$MgCl_2$ is Chaotropic, i.e. it destabilises biological macromolecules (non-linear)

Hallsworth JE, Yakimov MM, Golyshin PN, Gillion JLM, D'Auria G, de Lima Alves F, La Cono V, Genovese M, McKew BA, Hayes SL, Harris G, Giuliano L, Timmis KN, McGenity TJ (2007) Limits of life in $MgCl_2$-containing environments: chaotropicity defines a habitat. *Environ Microbiol* **9:** 801-813.

Understanding the effects of different salts, e.g. $MgSO_4$ on microbes (and their gas production)

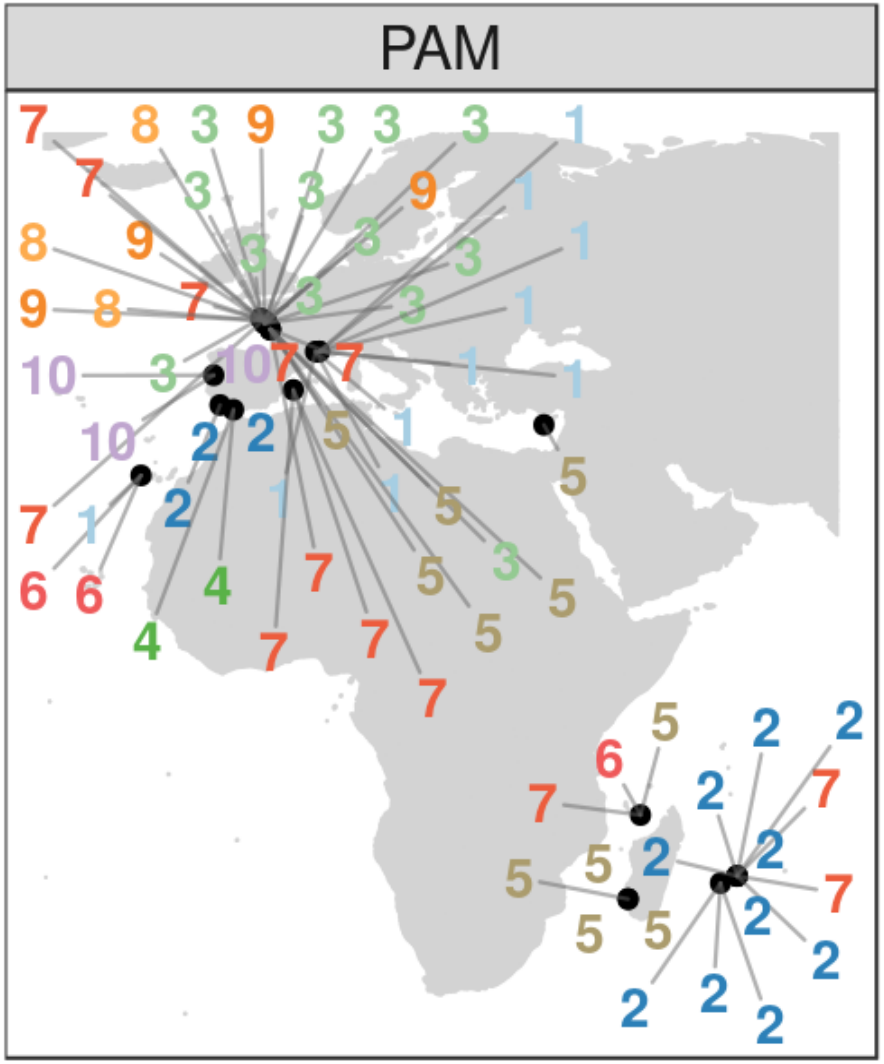


Mario Toubes at Basque Lake, BC, Canada – Magnesium sulfate rich lake

Distant salterns have similar halite-entombed archaeal communities

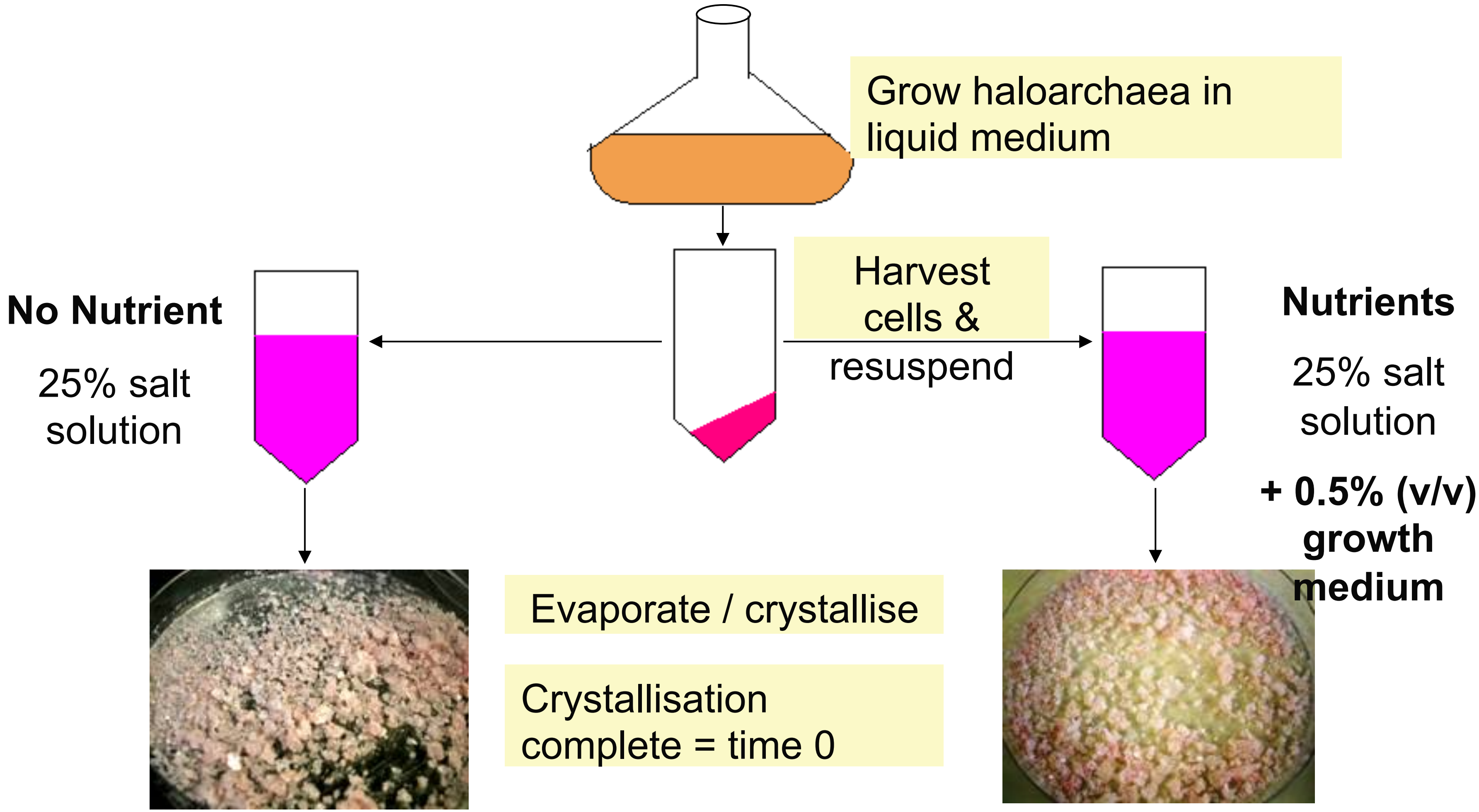
- Saltern halite in triplicate from 21 locations (~4 years old)

- Archaeal community analysis (using very high-throughput sequencing)



Clark DR, Mathieu M, Mourot L, Dufossé L, Underwood GJC, Dumbrell AJ, McGenity TJ (2017) Global Ecol Biogeog 26: 1435–1446.

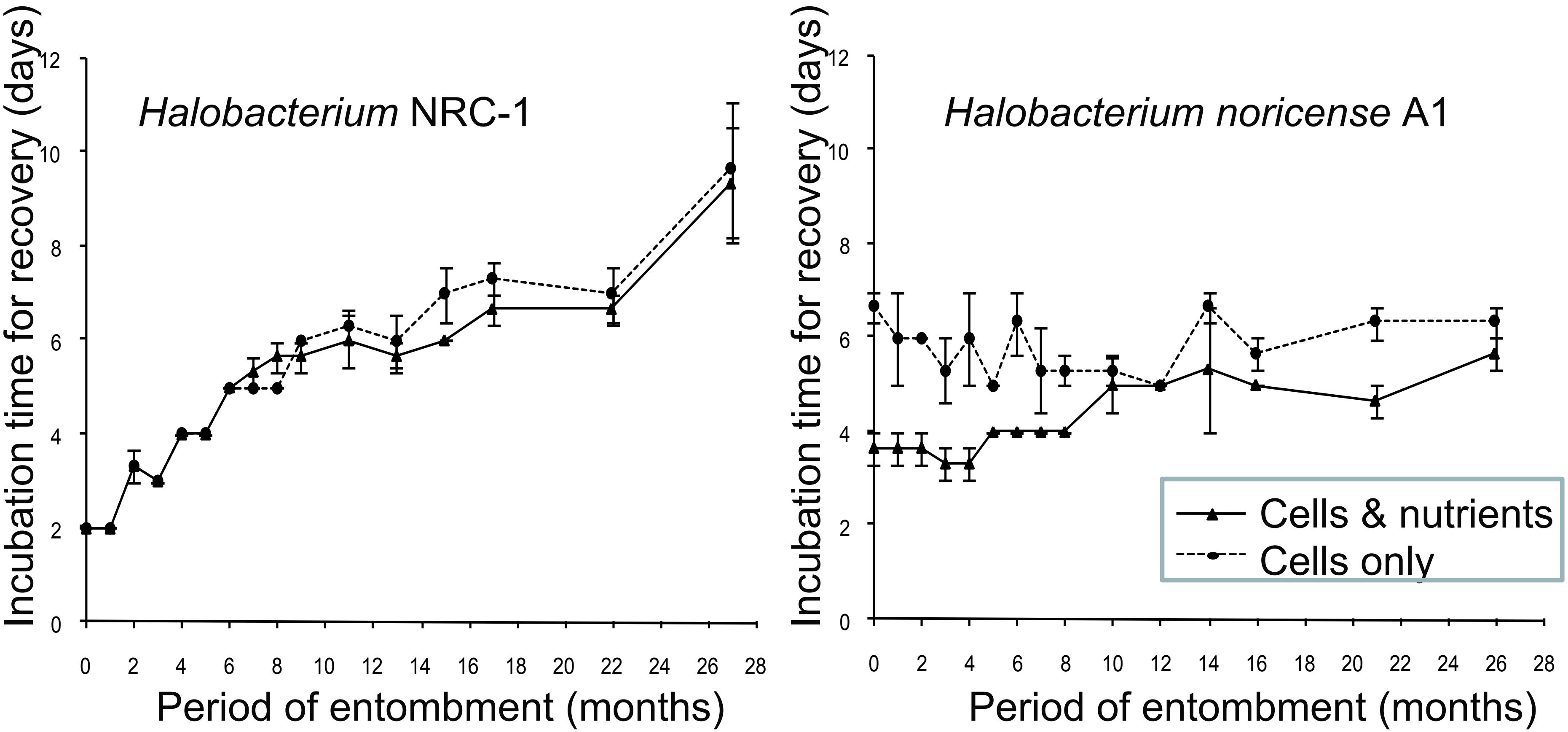
Which microbes survive best in lab-made halite?



Every month (later every two) dissolve crystals in growth medium and check daily for growth

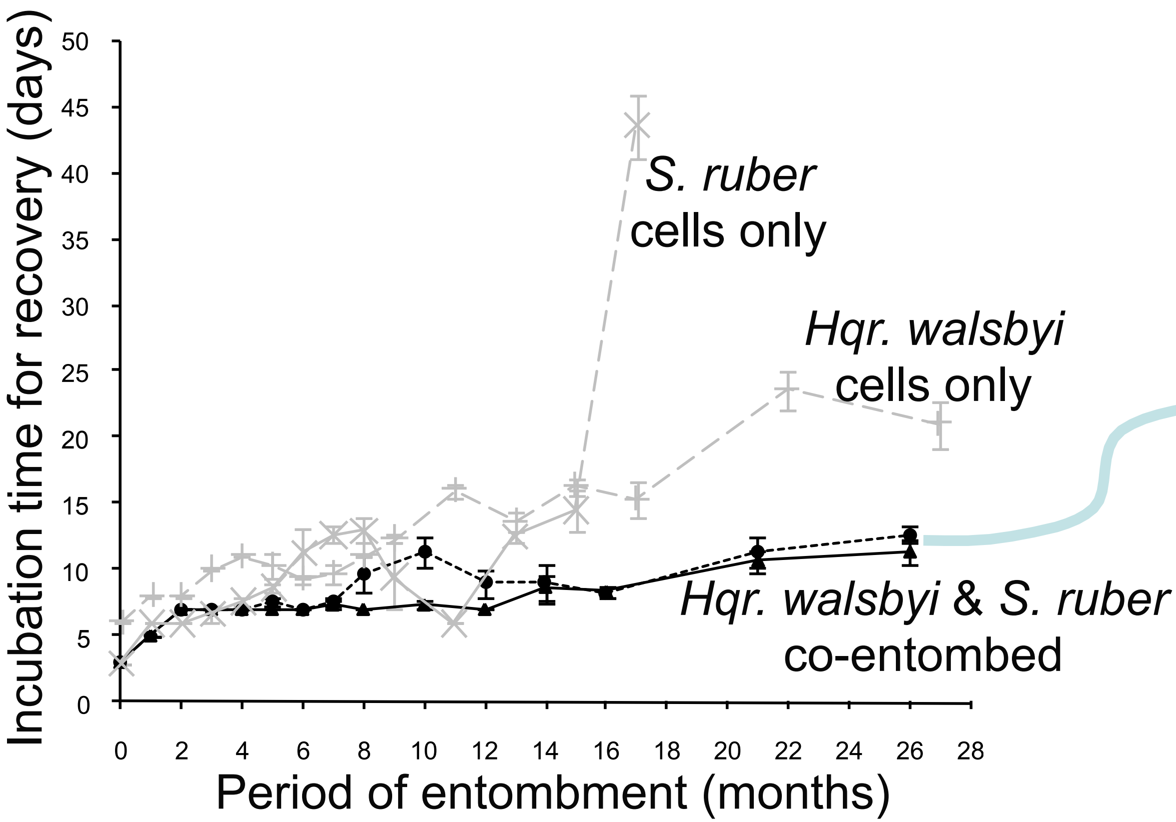
Halobacterium spp. are good at surviving inside halite

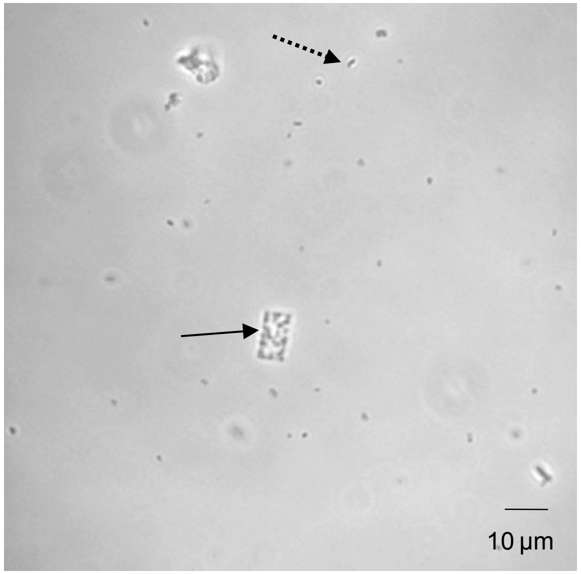
- *Halobacterium noricense* has no apparent loss of viability over 27 months



Gramain, A, Chong Díaz G, Demergasso C, Lowenstein TK, McGenity TJ (2011) Archaeal diversity along a subterranean salt core from the Salar Grande (Chile). *Environmental Microbiology* **13:** 2105–2121.

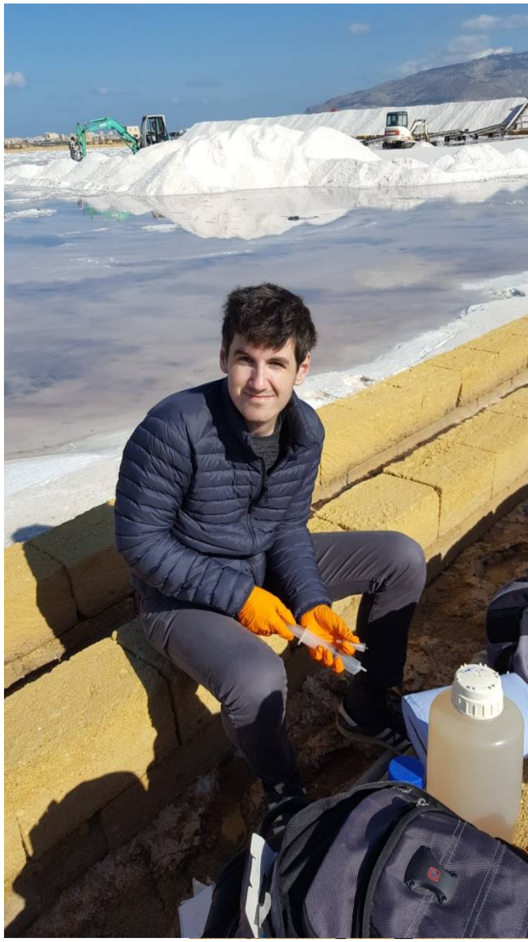
Co-entombment of *Haloquadratum walsbyi* & *Salinibacter ruber* enhances their survival

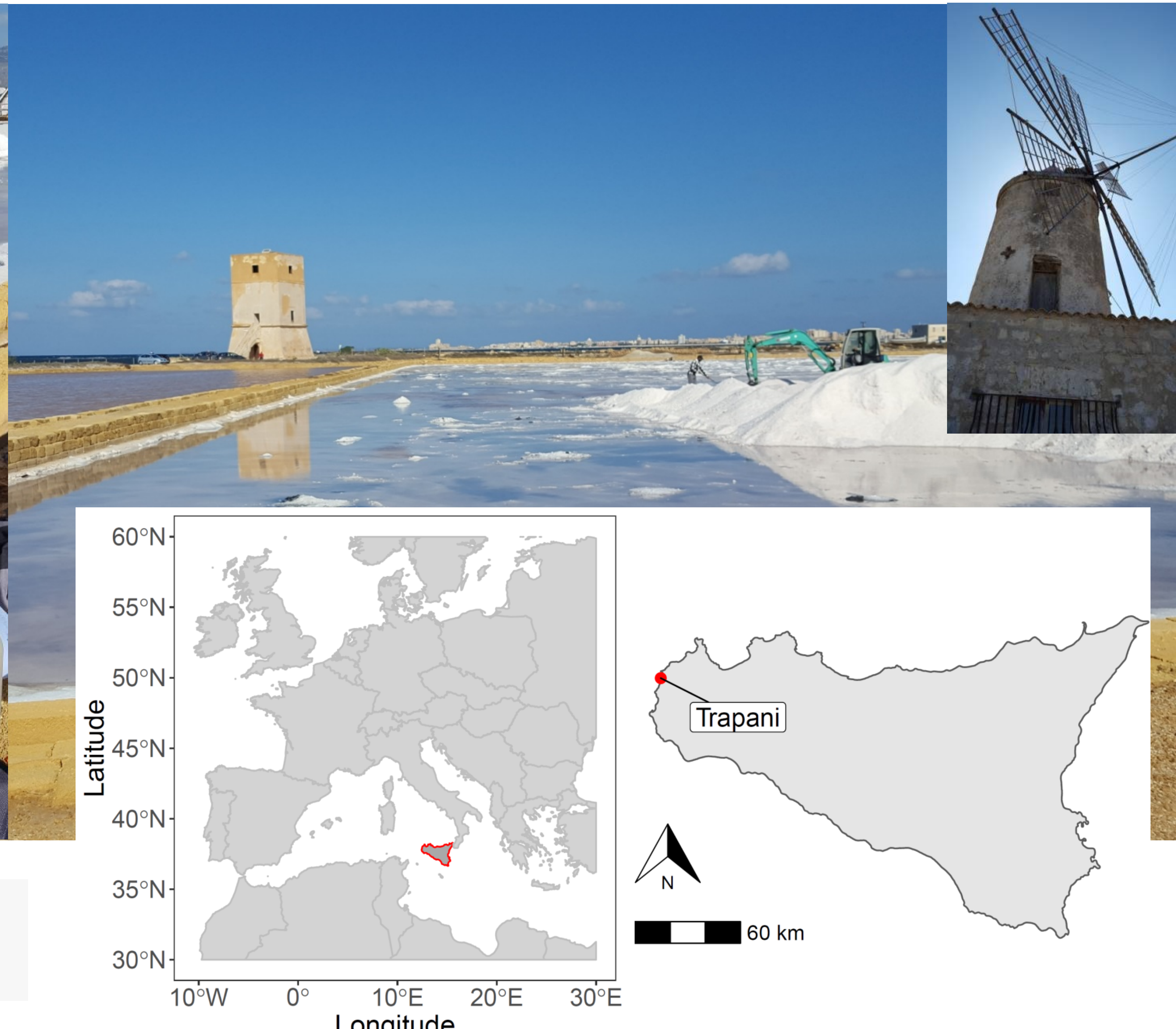




Gramain, A, Chong Díaz G, Demergasso C, Lowenstein TK, McGenity TJ (2011). *Environ Microbiol* **13:** 2105–2121.

Haloarchaea are uniformly entombed and survive equally as a community

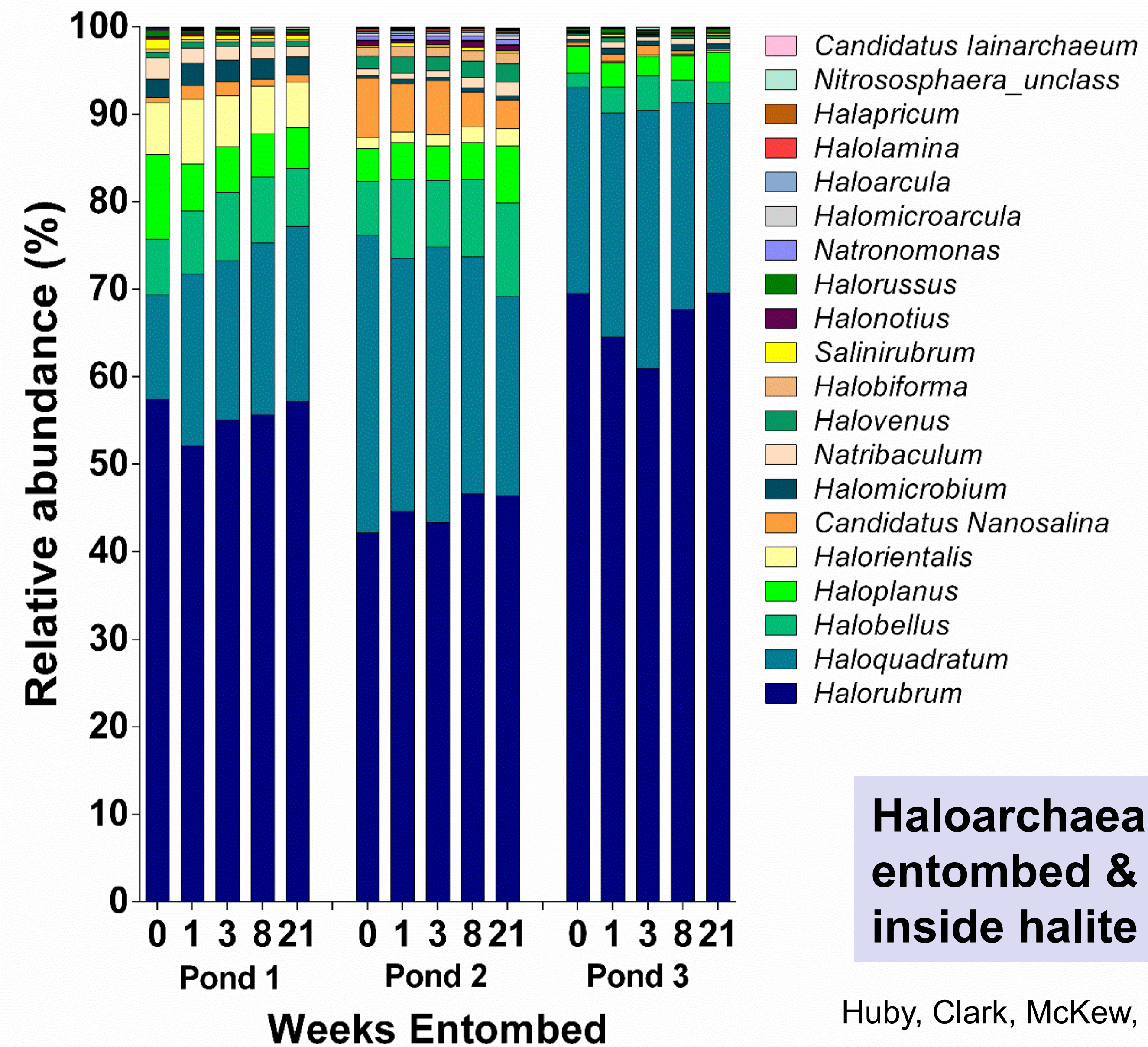




Tom Huby in Trapani’s salinas (Oct 2016)

Between-pond differences in Archaeal communities;

No significant change in Archaeal communities over time



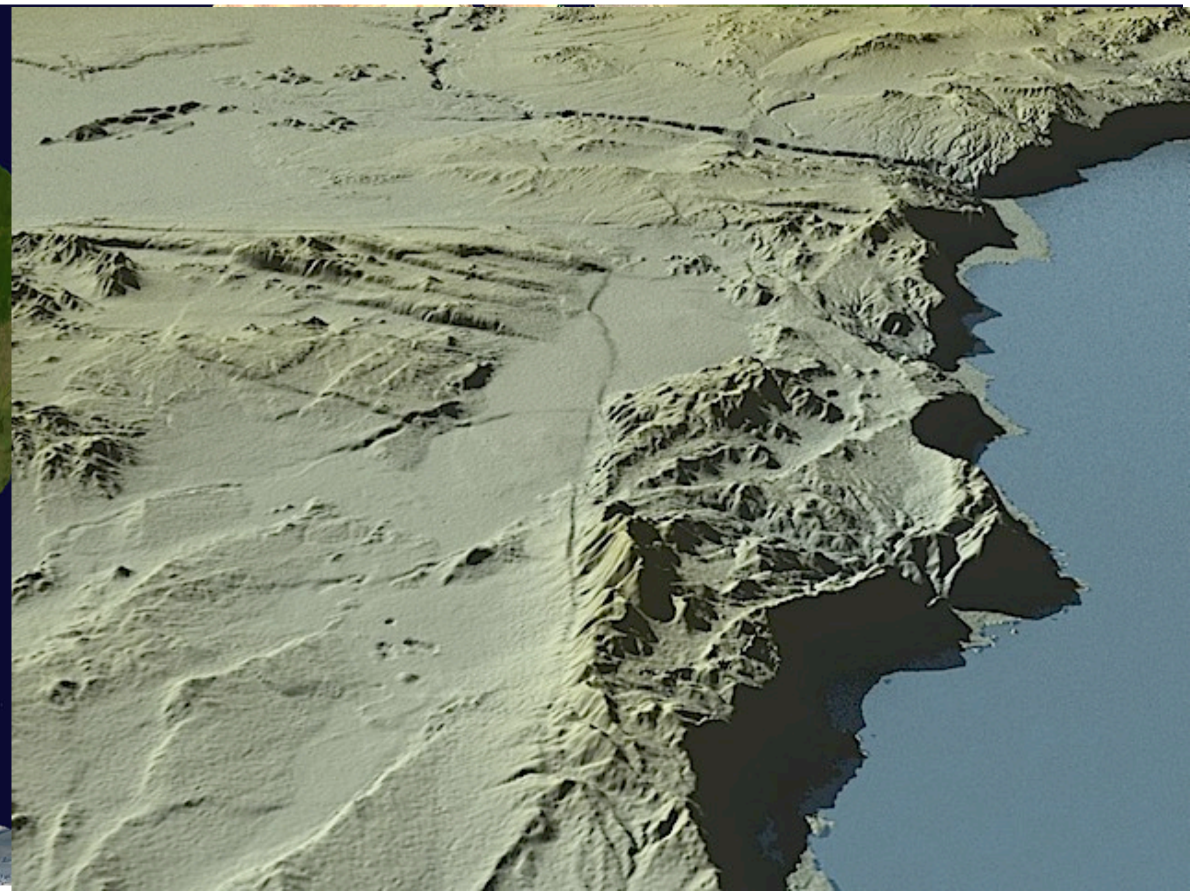
Haloarchaea are ~ uniformly entombed & survive equally inside halite over 21 weeks

Huby, Clark, McKew, McGenity subm.

How long can life exist in salt? – Salar Grande, Chile

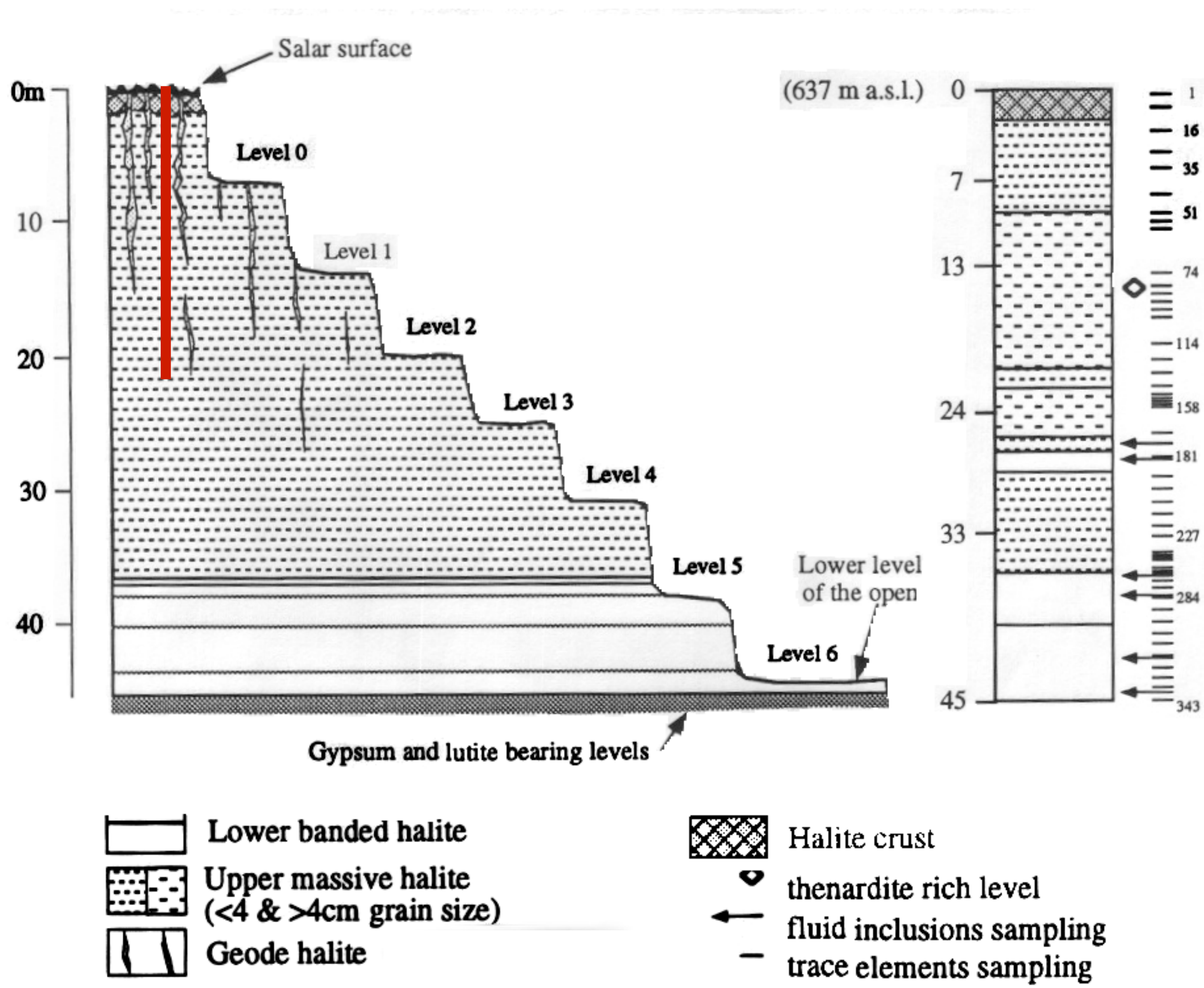
•45 x 5 km inter-montane basin

•Hydrologically inactive



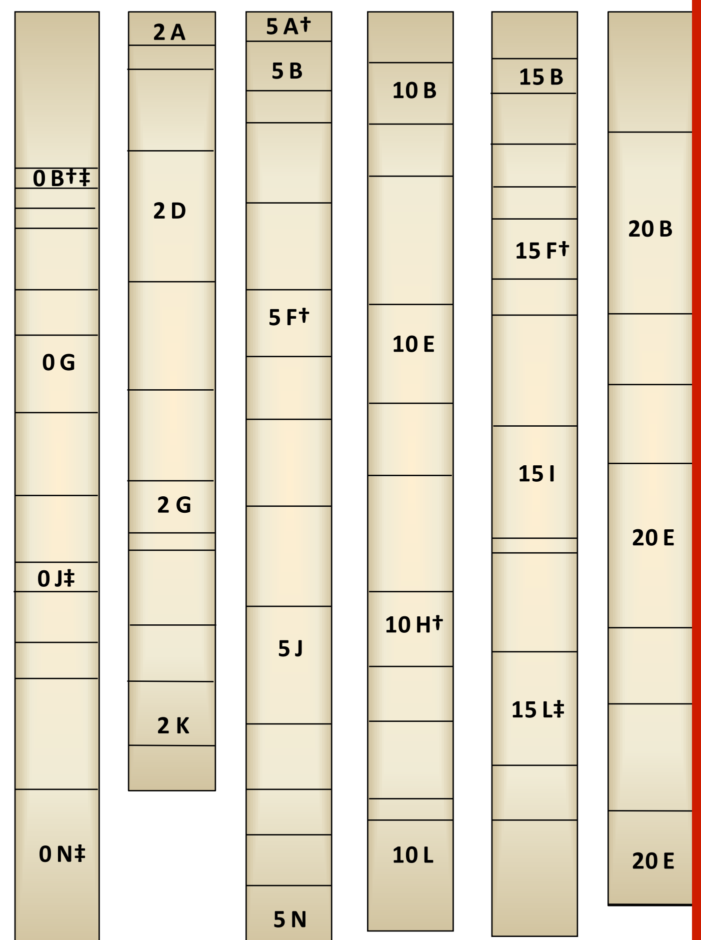
Gramain A et al. (2011) *Environ Microbiol* 13: 2105–2121.

25 metre core from G. Chong Diaz

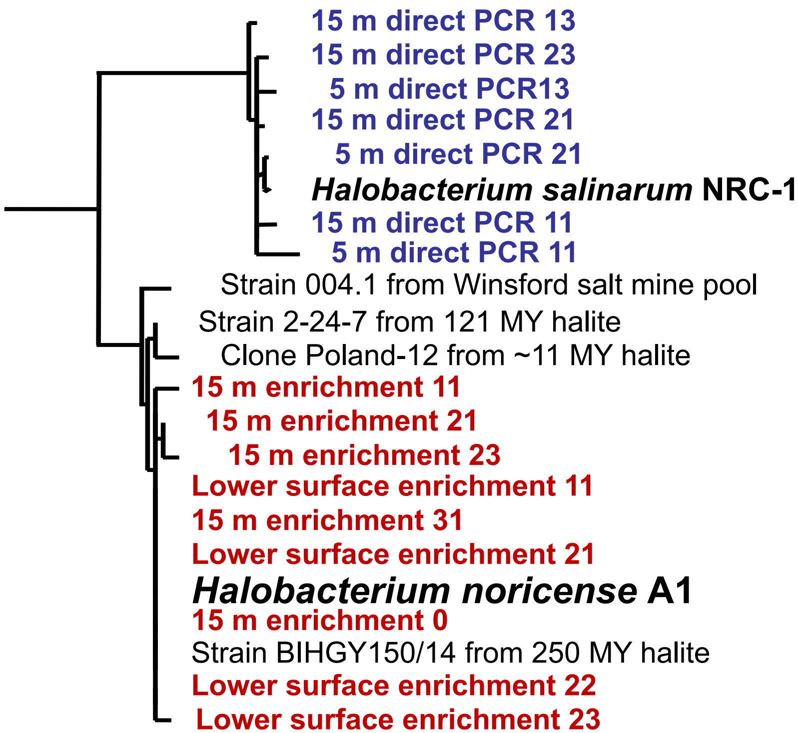


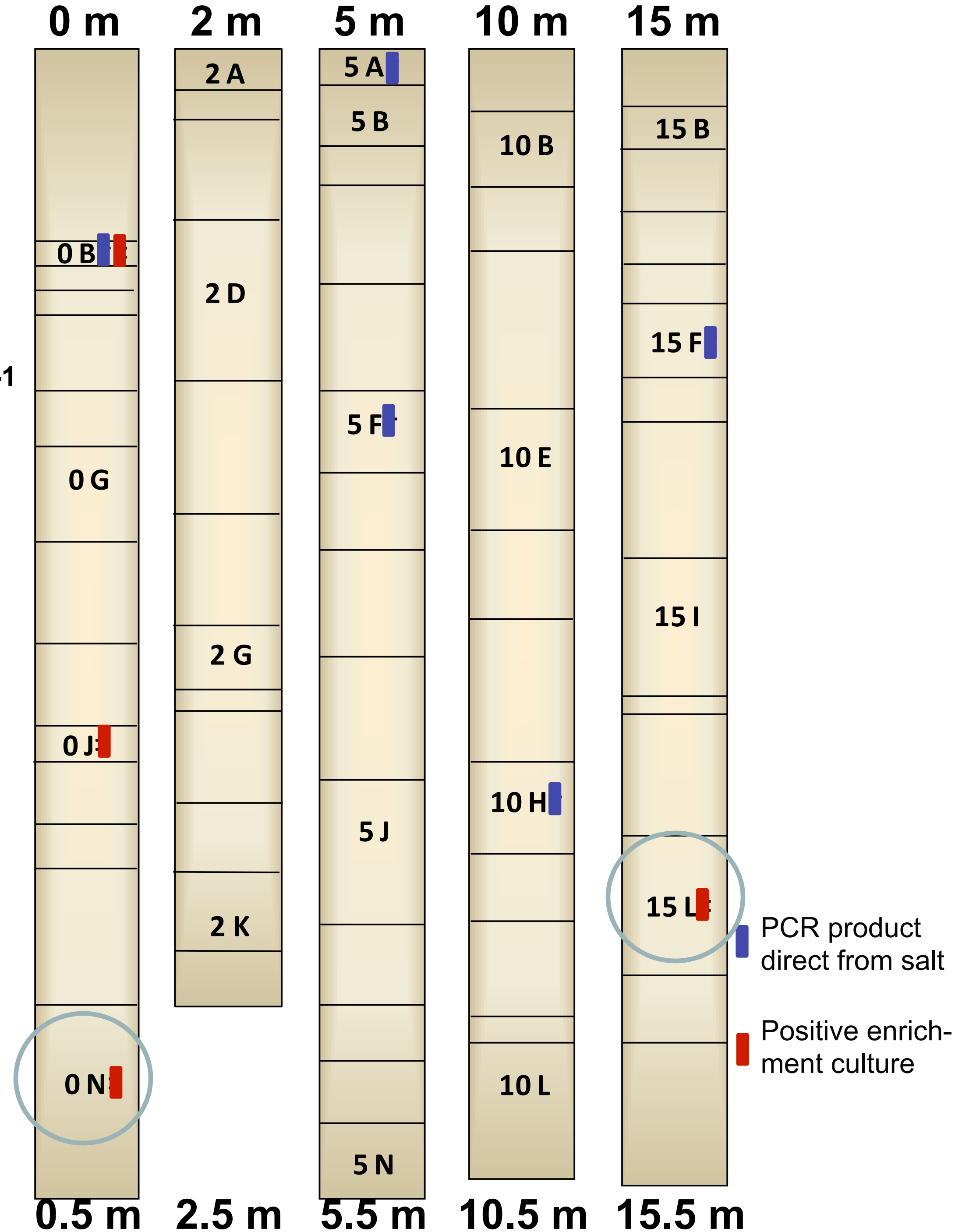
Chong Díaz et al. (1999) Palaeogeog Palaeoclim Palaeoecol 151: 39-54

Salar Grande core samples investigated by PCR of enrichment cultures & DNA extracted directly from the cores



Halobacterium noricense-like strains enriched from 15.4 m and 0.5 m depth





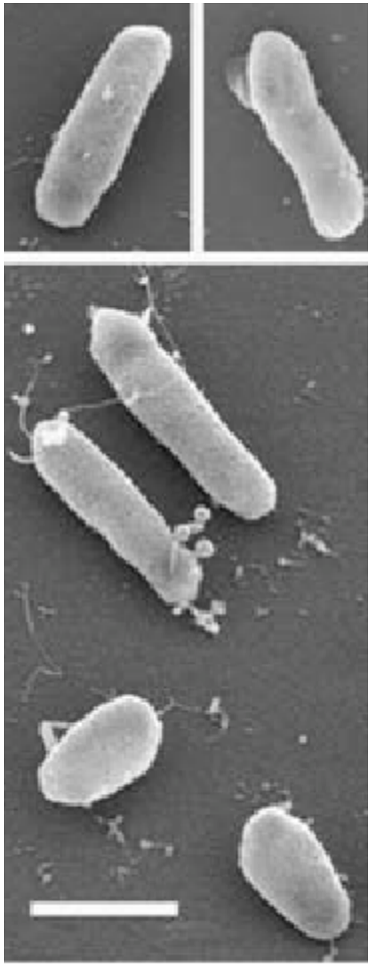
Gramain A et al. (2011) *Environ Microbiol* **13**:2105–2121

Halobacterium noricense & relatives isolated (i) or detected (d) in ancient halite

Country	Age of deposit (million years)
Chile	> 1.8 (i & d)
Poland	11-15.8 (d)
China	33.9-41.3 (i)
Brazil	121 (i & d)
China	123 (i)
Austria	250 (i & d)
USA	419 (d)

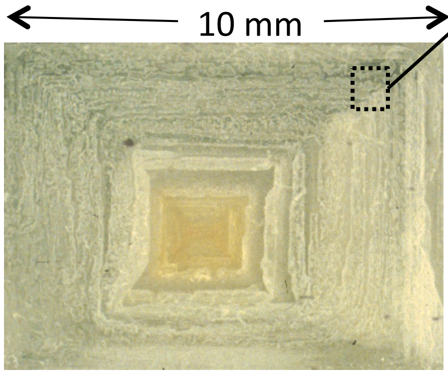
Are they as old as the salt?

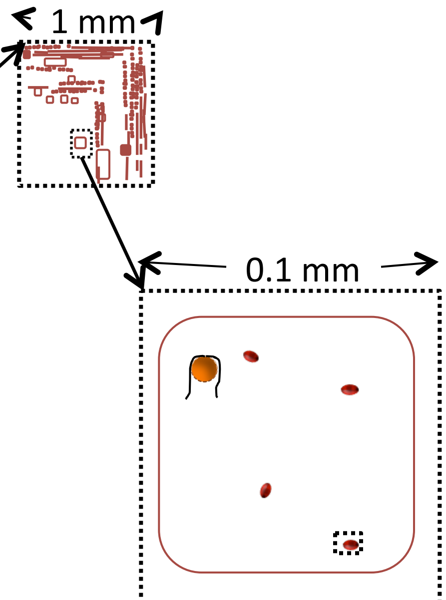
- Or, laboratory contamination?
- Or, recent contamination of the environment?
- Or, derived from populations trapped millions of years ago?
- Or, yes?



Gruber C et al. (2011)
Extremophiles **8:**431-439

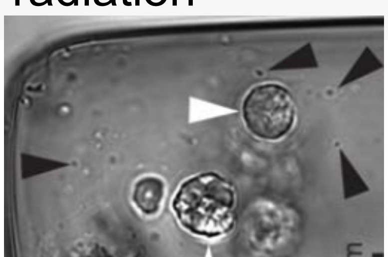
Features of living in halite that support long-term survival





Features of buried salt that enhance long-term survival

- Protection from radiation



Schubert et al. (2009)
34,000 year halite

Features of brine inclusions that enhance long-term survival

- Salt saturated
- Low oxygen concentration
- Co-entombed microbes as a source of carbon and energy

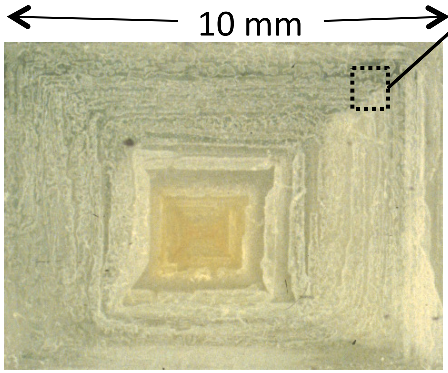
Carbon & Energy Requirements

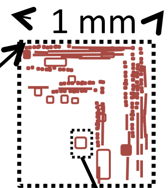
20°C over 100 million years a cell would need 50,000 times its own mass in C to avoid DNA depurination (Price and Sowers 2004)

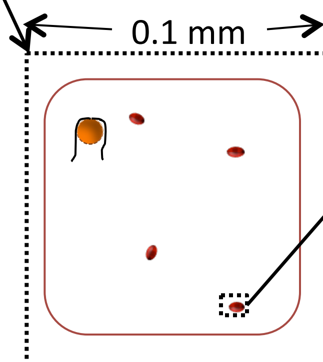
A100 μm cube inclusion with a1:20 cell:brine ratio would have with 50,000 cells (McGenity et al. 2008)

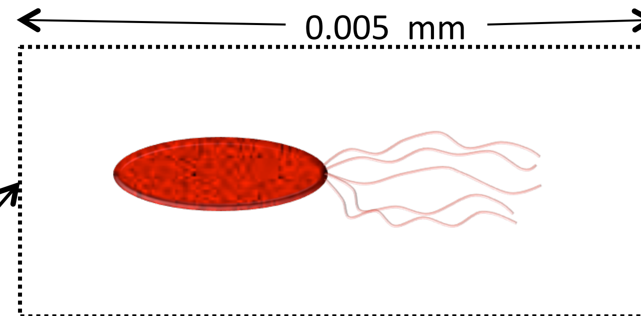
One *Dunaliella salina* cell would provide enough C & energy for a single miniaturized cell to survive for 12 million years (Oren 2016)

Features of *Halobacterium* spp. and living in halite that allow for long-term survival









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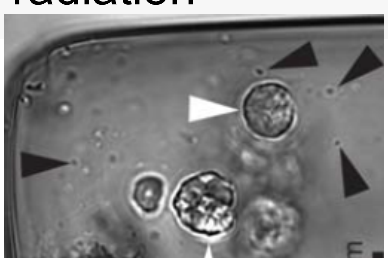

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Features of brine inclusions that enhance long-term survival

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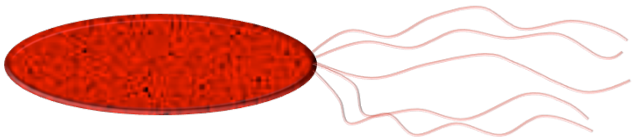
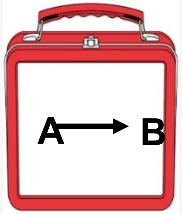
Features of *Halobacterium* that enhances long-term survival

Features of *Halobacterium* spp. that support long-term survival



Metabolism



- Anaerobic metabolism
- Diverse C & energy sources
- Storage compounds (e.g. PHA; DNA)
- Cell miniaturisation (energy limitation)
- Archaeol (non-leaky) lipids

Protective Cellular Environment – Damage Avoidance

- High K^+ and halide concentrations
- High Manganese : Iron
- Manganese antioxidant complexes
- Carotenoids
- DNA with high G&C content
- ROS-protecting enzymes

Efficient Repair Mechanisms

- Photo-reactivation
- Nucleotide excision repair
- Base excision repair
- Homologous recombination (polyploidy)

Thanks to

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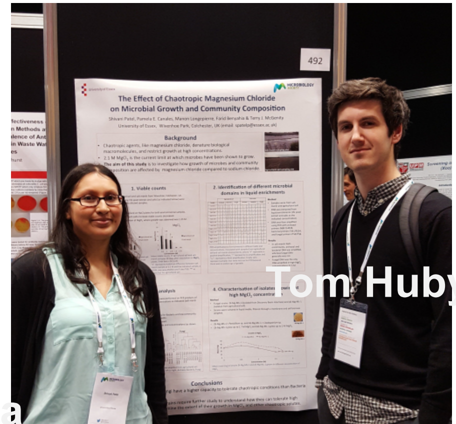
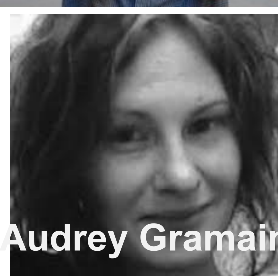




University of Essex

Project funded by the EUROPEAN UNION

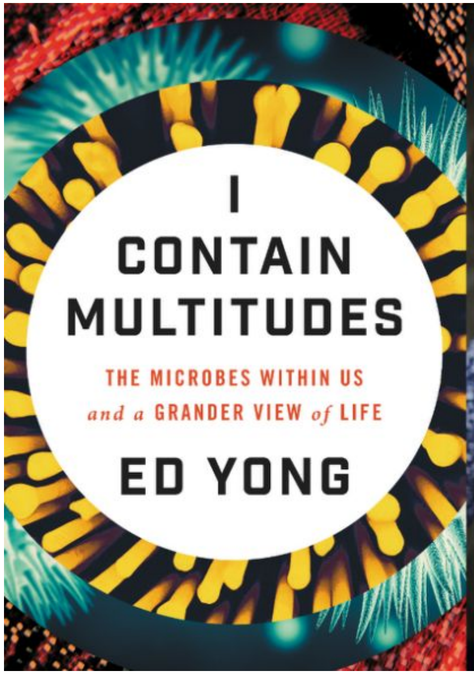
UK SPACE AGENCY

NERC SCIENCE OF THE ENVIRONMENT

SALTGIANT Understanding the Mediterranean Salt Giant

MedSalt

A good general read



WP2 Deep Life

ESR 9

Long-term survival of microbes in halite

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