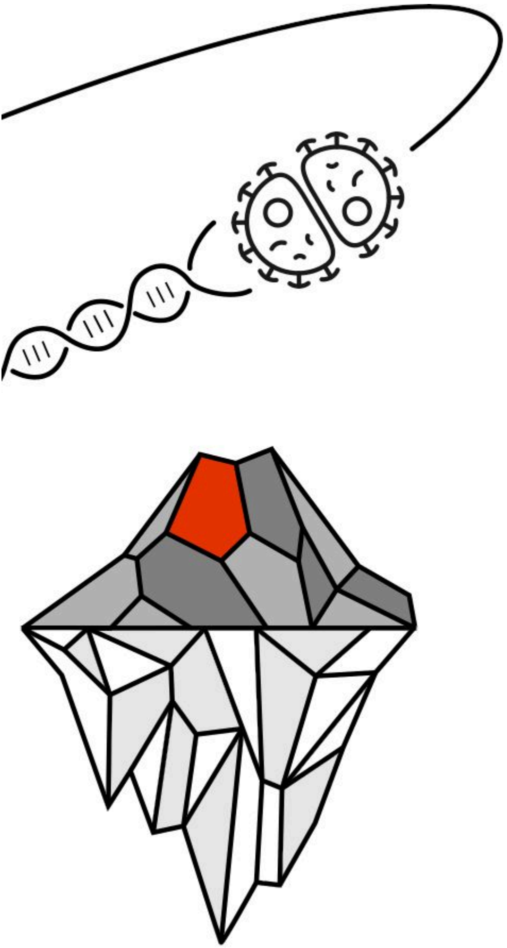

MICROBIOLOGY OF EXTREME ENVIRONMENTS

Extremophiles: Acidic, alkaline and saline environments

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GIOVANNELLI LAB

BIOLOGY OF EXTREME ENVIRONMENTS

DIPARTIMENTO DI BIOLOGIA

Acidity and alkalinity

pH determines which species survives

Grand Prismatic Spring, Yellowstone Park (Wyoming)
https://www.livescience.com/47263-grand-prismatic-hot-spring-photos.html

Every microorganism has a pH range, typically about 2–3 pH units, within which growth is possible.

Acidity and alkalinity dependent extremophiles. Who are they?

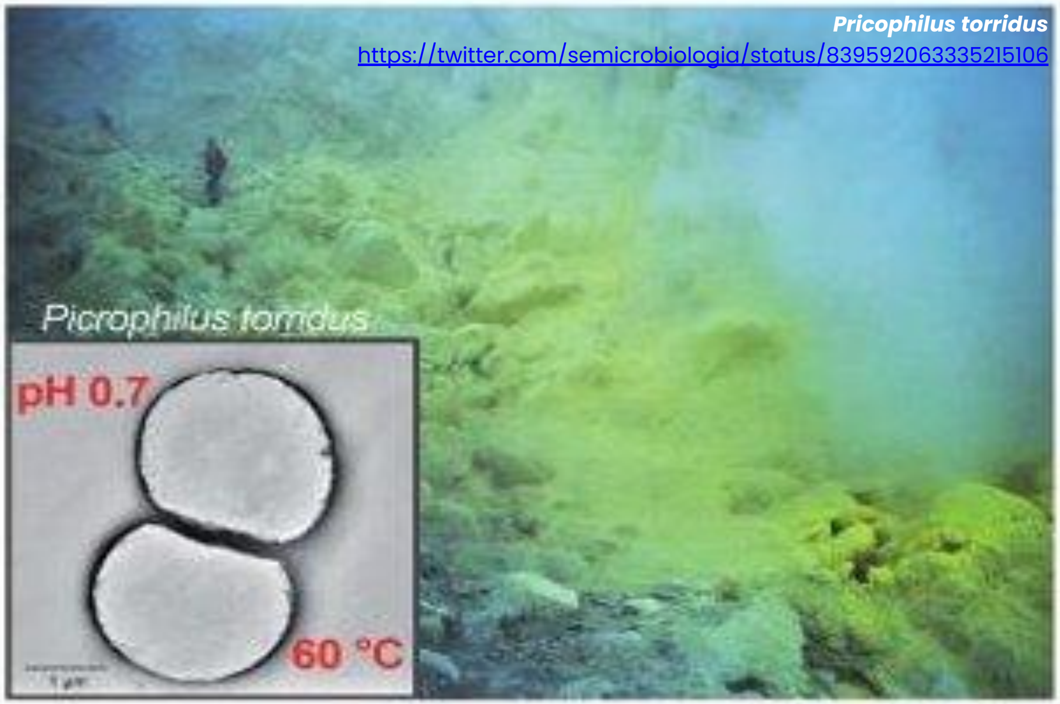
Extremophiles

pH

Hyperacidophile (pH < 3)

Picrophilus oshimae
P. torridus
(pH_{opt}=0.7)

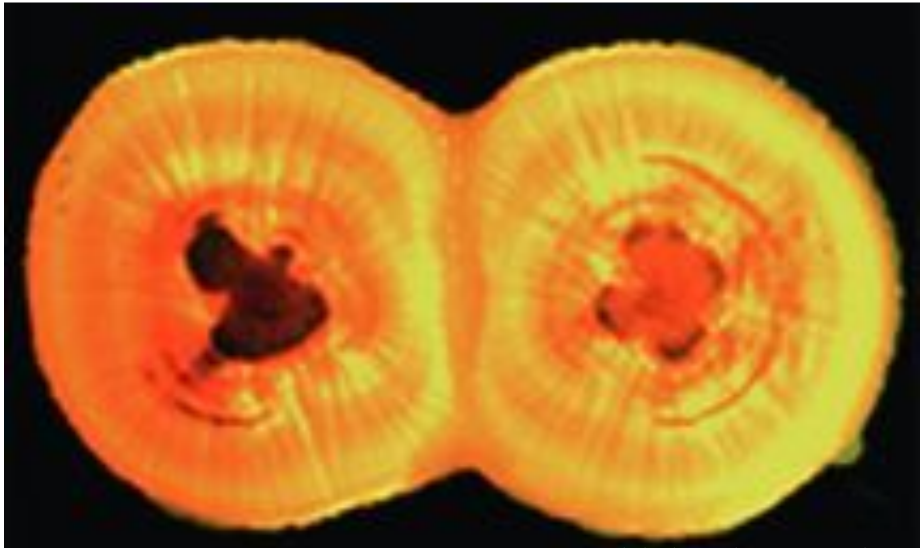
Solfataric hot spring in Noboribetsu (Japan)



Acidity and alkalinity dependent extremophiles. Who are they?

Extremophiles → pH

Hyperacidophile (pH < 3)	*Picrophilus oshimae* *P. torridus* (pH_{opt}=0.7)	Solfataric hot spring in Noboribetsu (Japan)
Acidophile (pH <5)	*Acidithiobacillus ferrooxidans*	Coal mine drainage (USA)



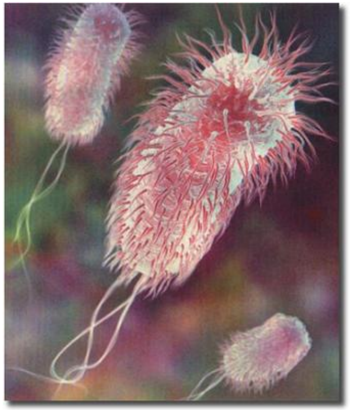
Acidithiobacillus ferrooxidans
(Quatrini and Johnson (2019) Trends in Microbiology, vol. 27, 282-283)

Acidity and alkalinity dependent extremophiles. Who are they?

Extremophiles

pH

- **Hyperacidophile (pH < 3)** — *Picrophilus oshimae*, *P. torridus* (pH_{opt}=0.7) — Solfataric hot spring in Noboribetsu (Japan)
- **Acidophile (pH <5)** — Acidithiobacillus ferrooxidans — Coal mine drainage (USA)
- **Neutrophile (pH 5-9)** — *Escherichia coli* (pH_{opt}=7)



Escherichia coli

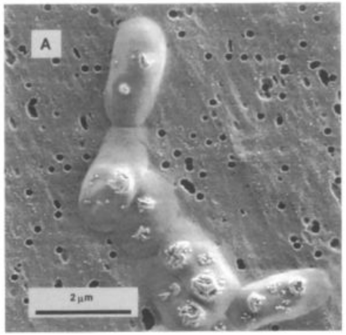
[U.S. Environmental Protection Agency]

Acidity and alkalinity dependent extremophiles. Who are they?

Extremophiles

pH

Hyperacidophile (pH < 3)	*Picrophilus oshimae* *P. torridus* (pH_{opt}=0.7)	Solfataric hot spring in Noboribetsu (Japan)
Acidophile (pH <5)	Acidithiobacillus ferrooxidans	Coal mine drainage (USA)
Neutrophile (pH 5-9)	*Escherichia coli* (pH_{opt}=7)	
Alkaliphile (pH >9)	*Halomonas campisalis* (pH_{opt}=9.5)	Soap Lake, Washington (USA)



Acidity and alkalinity dependent extremophiles. Who are they?

Extremophiles — pH

Hyperacidophile (pH < 3)	*Picrophilus oshimae* *P. torridus* (pH_{opt}=0.7)	Solfataric hot spring in Noboribetsu (Japan)
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Alkaliphile (pH >9)	*Halomonas campisalis* (pH_{opt}=9.5)	Soap Lake, Washington (USA)
	Oceanobacillus iheyensis HTE831	*Deep sea mud*

Acidity and alkalinity dependent extremophiles. Who are they?

Extremophiles — pH

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	Oceanobacillus iheyensis HTE831	*Deep sea mud*
Hyperalkaliphile (pH >11)	*Serpentinomonas* sp. B1 (pH_{opt}=11)	Serpentinizing system, The Cedars, California(USA)

Acidity and alkalinity dependent extremophiles. Who are they?

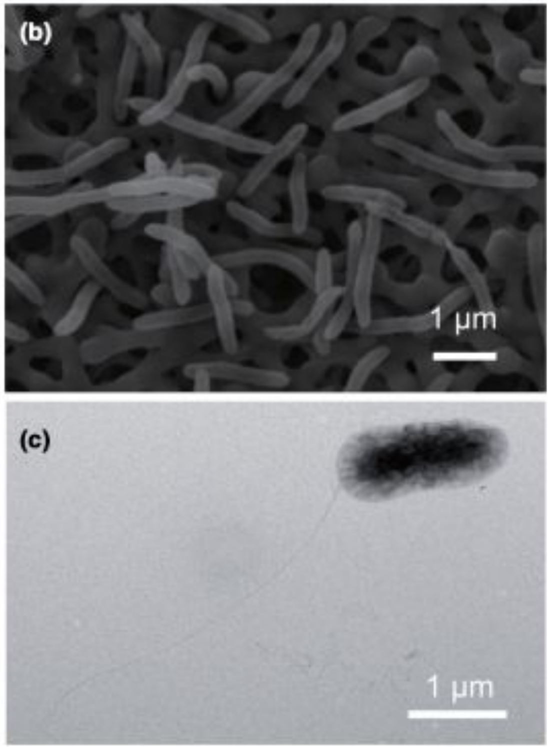
Extremophiles

pH

- **Hyperacidophile (pH < 3)**
- **Acidophile (pH <5)**
- **Neutrophile (pH 5-9)**
- **Alkaliphile (pH >9)**
- **Hyperalkaliphile (pH >11)**

Serpentinomonas sp. B1 (pH_{opt}=11)

Serpentinizing system, The Cedars, California(USA)



Acidity and alkalinity dependent extremophiles. Who are they? The <u>*“known”*</u> extremes

INTERNATIONAL JOURNAL OF SYSTEMATIC BACTERIOLOGY, July 1996, p. 814–816 Vol. 46, No. 3
0020-7713/96/$04.00+0

Picrophilus oshimae and *Picrophilus torridus* fam. nov., gen. nov., sp. nov., Two Species of Hyperacidophilic, Thermophilic, Heterotrophic, Aerobic Archaea

CHRISTA SCHLEPER, GABRIELA PÜHLER, HANS- PETER KLENK, AND WOLFRAM ZILLIG*

Max Plank Institut für Biochemie, D-82152 Martinsried, Germany

We describe two species of hyperacidophilic, thermophilic, heterotrophic, aerobic archaea that were isolated from solfataric hydrothermal areas in Hokkaido, Japan. These organisms, *Picrophilus oshimae* and *Picrophilus torridus*, represent a novel genus and a novel family, the *Picrophilaceae*, in the kingdom *Euryarchaeota* and the order *Thermoplasmales*. Both of these bacteria are more acidophilic than the genus *Thermoplasma* since they are able to grow at about pH 0.

Acidity and alkalinity dependent extremophiles. Who are they? The *"known"* extremes

nature COMMUNICATIONS

ARTICLE

Received 17 Dec 2013 | Accepted 16 Apr 2014 | Published 21 May 2014 DOI: 10.1038/ncomms4900 OPEN

Physiological and genomic features of highly alkaliphilic hydrogen-utilizing *Betaproteobacteria* from a continental serpentinizing site

Shino Suzuki[1], J. Gijs Kuenen[2,3], Kira Schipper[1,3], Suzanne van der Velde[2,3], Shun'ichi Ishii[1], Angela Wu[1], Dimitry Y. Sorokin[3,4], Aaron Tenney[1], XianYing Meng[5], Penny L. Morrill[6], Yoichi Kamagata[5], Gerard Muyzer[3,7] & Kenneth H. Nealson[1,2]

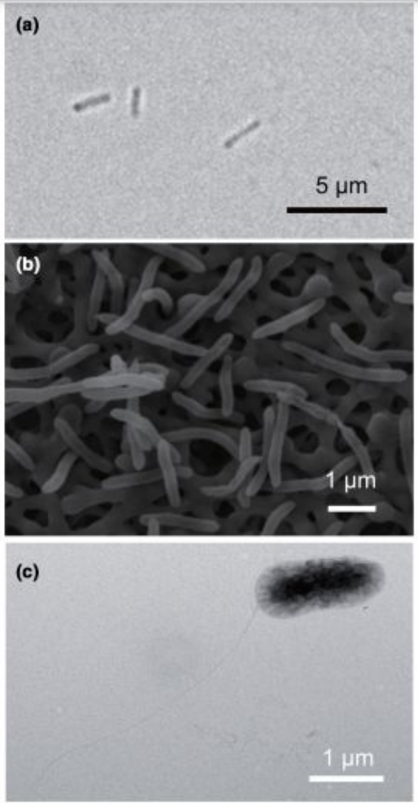


Fig. 3. Microscopic observation of strain A1^T. (a) Phase contrast microscopy image of strain A1^T grown on acetate and oxygen. The three strains are visually indistinguishable. (b) SEM image of strain A1^T on carbon filter paper. Morphologies are indistinguishable for the three strains. (c) TEM image of strain A1^T grown on acetate with oxygen.

Acidity and alkalinity dependent extremophiles. Interactions with other parameters

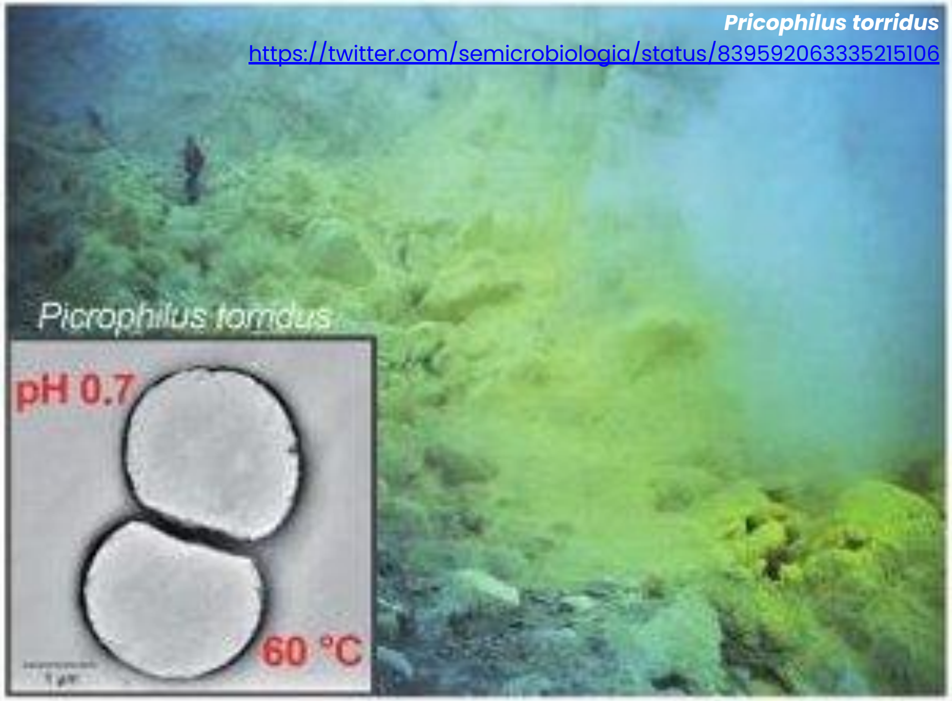
Acidophiles

Temperature

✔ High temperatures:

Acido-thermophiles like

Picrophilus torridus



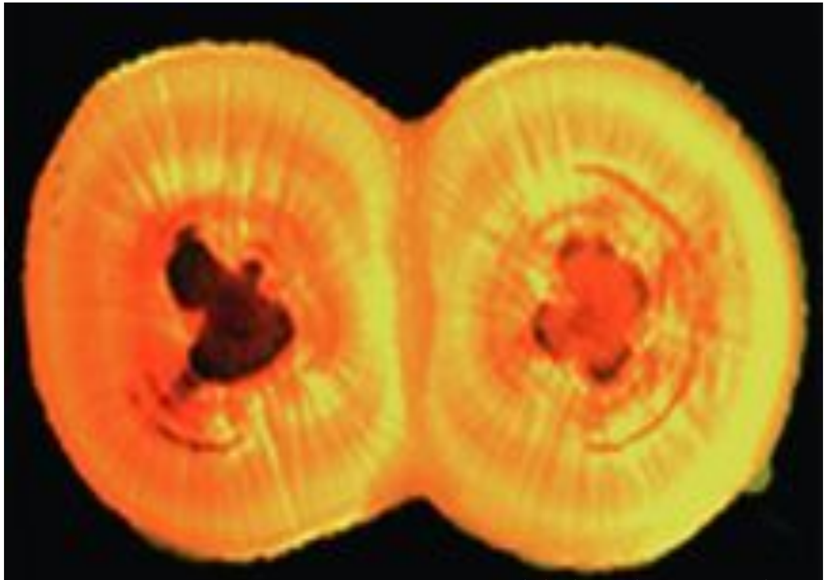
Pricophilus torridus
https://twitter.com/semicrobiologia/status/839592063335215106

Acidity and alkalinity dependent extremophiles. Interactions with other parameters

Acidophiles

Temperature

✔ Low temperatures (<5ºC): Psychro-tolerant *Acidithiobacillus ferrooxidans* and *Acidophilium* (Quatrini and Johnson, 2018)



Acidithiobacillus ferrooxidans
(Quatrini and Johnson (2019) Trends in Microbiology, vol. 27, 282-283)

Acidity and alkalinity dependent extremophiles. Interactions with other parameters

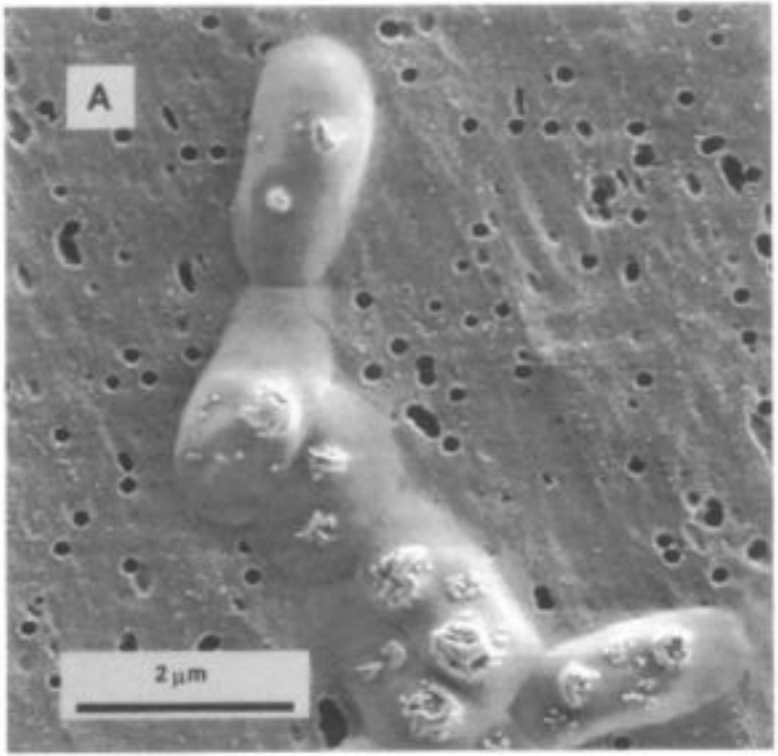
Alkaliphiles

<u>Salt concentration:</u>

- ✔ Halo-alkaliphiles

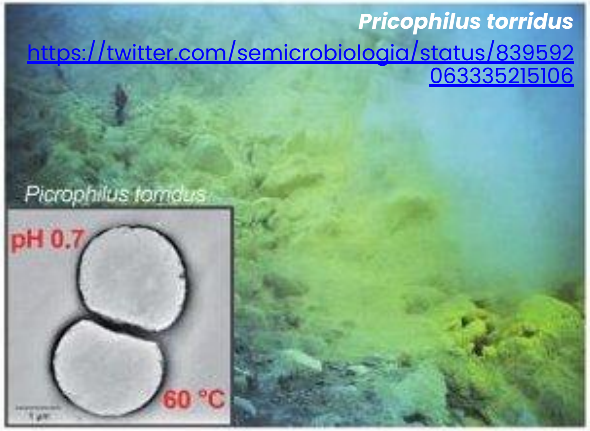
<u>Low water activity:</u>

- ✔ Xero-tolerant alkaliphiles

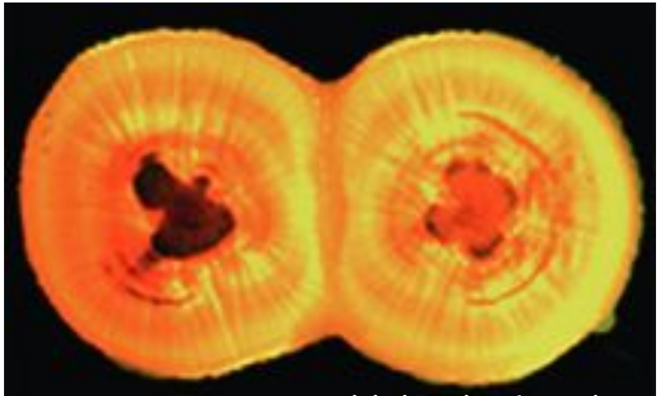


Scanning electron microphotograph of *Halomonas campisalis* (Mormile et al. 1999)

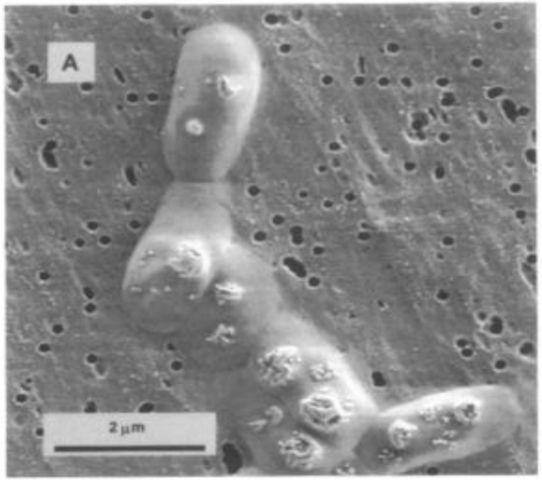
Acidity and alkalinity dependent extremophiles. Interactions with other parameters



Pricophilus torridus
https://twitter.com/semicrobiologia/status/839592063335215106



Acidithiobacillus ferrooxidans
(Quatrini and Johnson (2019) Trends in Microbiology, vol. 27,



Scanning electron microphotograph of *Halomonas campisalis* (Mormile et al. 1999)

Tolerance or preference for more than one parameter can allow the expansion of the extremophile ecological niche.

Acidity and alkalinity : Physiology

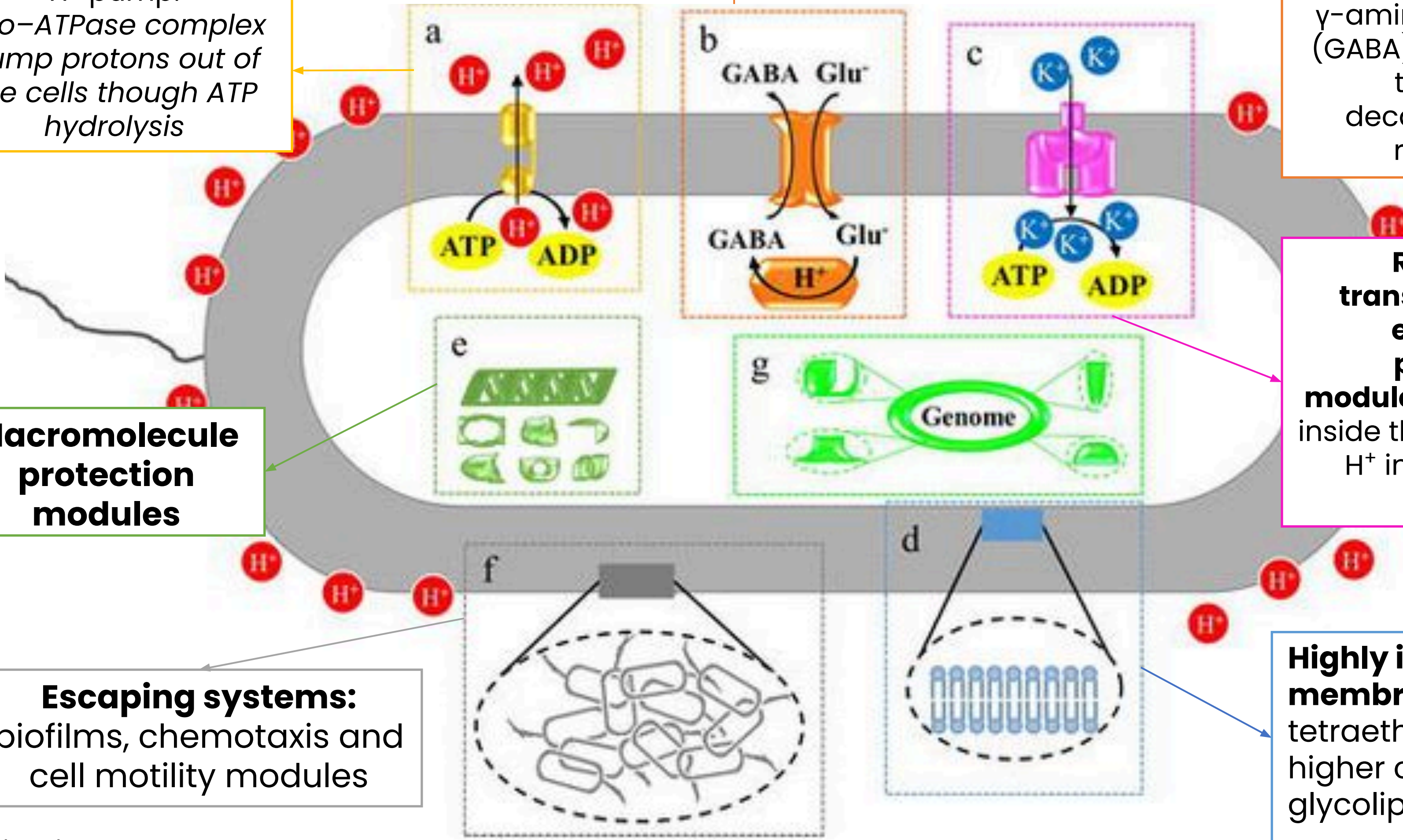
How can acidophiles thrive at low pH?

active and passive acid-resistance mechanisms

The active and passive acid-resistance mechanisms in acidophiles

H^+ pump: *F_1Fo–ATPase complex pump protons out of the cells though ATP hydrolysis*

H^+ consumption Module: the transformation of glutamate to γ-aminobutyric acid (GABA) consumes H^+ thanks to decarboxylation reactions



Reversed transmembrane electrical potential modules (positive Δψ inside the cell prevents H^+ into the cells)

Macromolecule protection modules

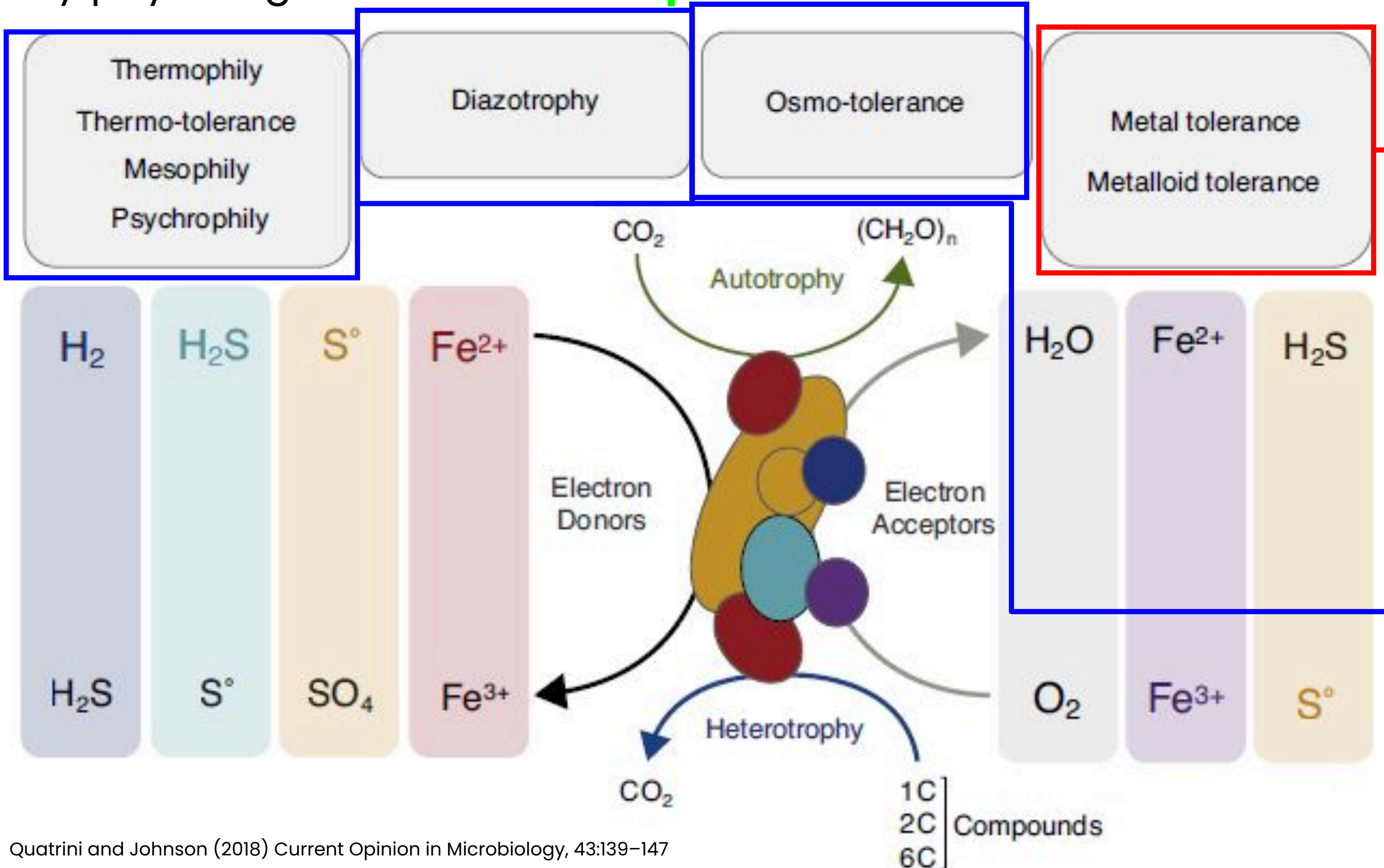
Escaping systems: biofilms, chemotaxis and cell motility modules

Highly impermeable membranes system: tetraether lipids, higher content of glycolipids

Chen (2021) Thriving at Low pH: Adaptation Mechanisms of Acidophiles
http://dx.doi.org/10.5772/intechopen.96620

Acidity and alkalinity : Physiology

Key physiological traits of **acidophilic** communities



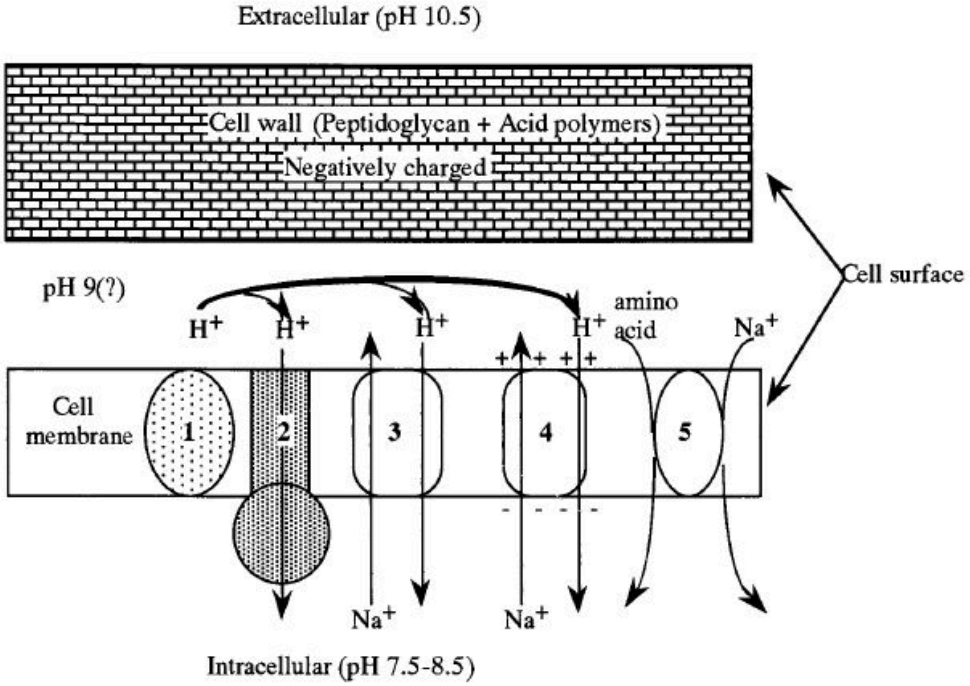
Conserved across acidophilic lineages

Partitions differently between taxa

Quatrini and Johnson (2018) Current Opinion in Microbiology, 43:139–147

Acidity and alkalinity : Physiology

How alkaliphilic microorganisms can grow in such an extreme environment?



1: Respiratory chain; 2: FoF1-ATPase

3: ΔpH dependent Na^+ / H^+ antiporter

4: $\Delta\psi$ dependent Na^+ / H^+ antiporter

5: Amino acids/Na^+ symporter

Horikoshi (1999) Microbial Mol Biol Rev 63(4): 735–750.

Acidity and alkalinity : Physiology

How alkaliphilic microorganisms can grow in such an extreme environment?

- ✔ pH inside the cell is maintained around 8;
- ✔ Cell wall of many alkaliphiles composed of acidic polymers: The negative charges on the acidic non-peptidoglycan components may give the cell surface its ability to adsorb Na^+ and H^+ ions and repulse OH^- ions;
- ✔ Efflux of Na^+ generates a Na^+ motive force that helps with solute transportation inside the cell and with the removal of toxins;
- ✔ Plasma membranes may also maintain pH homeostasis by using the Na^+/H^+ antiporter system (ΔpH and $\Delta\psi$ dependent), the K^+/H^+ antiporter, and ATPase-driven H^+ expulsion.

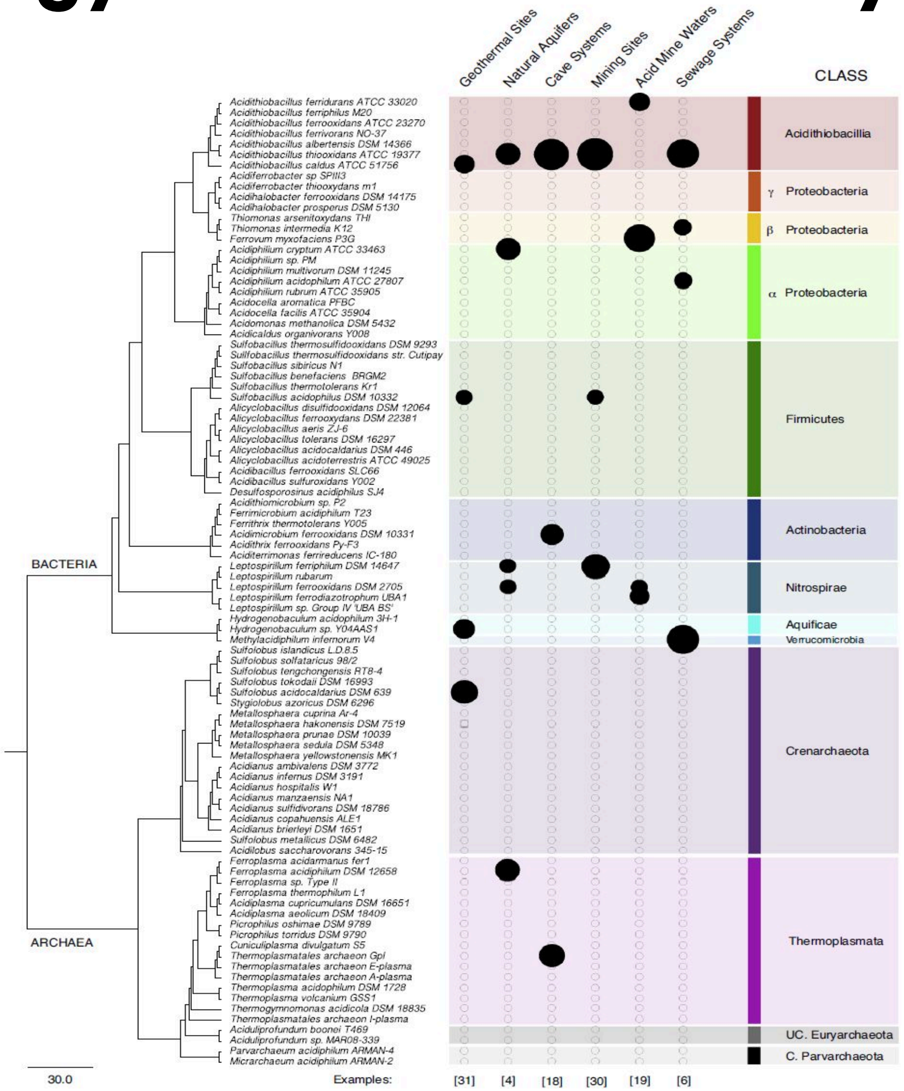
Horikoshi (1999) Microbial Mol Biol Rev 63(4): 735–750.

ACIDOPHILIC AND EXTREMELY ACIDOPHILIC MICROBIAL DIVERSITY

Acidity and alkalinity: Ecology – Microbial diversity

Extremely acidophilic organisms are exclusively microbial and include both Bacteria and Archaea, like:

Acidithiobacilia
γ-proteobacteria
β-proteobacteria
α-proteobacteria
Firmicutes
Actinobacteria
Nitrospirae
Acquificae
Verrucomicrobia
Chrenarchaeota
Thermoplasmata
Euryarchaeota
Paryarchaeota



Quatrini and Johnson (2018) Current Opinion in Microbiology, 43:139–147

Acidity and alkalinity: Ecology – Microbial diversity

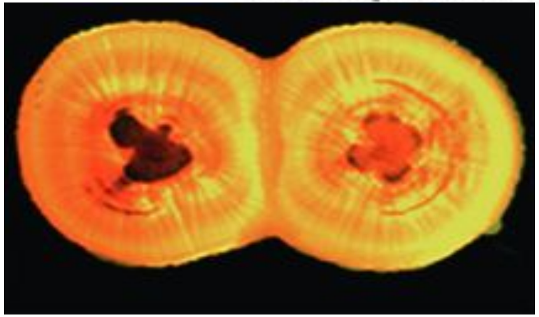
Chemolithoautotrophy

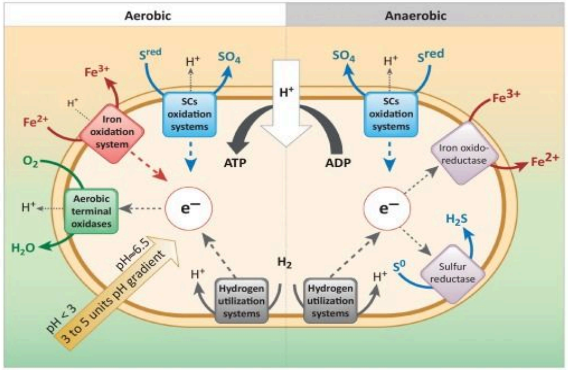
MICROÖRGANISMS CONCERNED IN THE OXIDATION OF SULFUR IN THE SOIL

II. THIOBACILLUS THIOOXIDANS, A NEW SULFUR-OXIDIZING ORGANISM ISOLATED FROM THE SOIL

SELMAN A. WAKSMAN AND J. S. JOFFE

Received for publication June 16, 1921





Acidothiobacillus (At.) thiooxidans: **First** and **most well studied** hyper-acidophilic microorganism

Isolated and characterized in 1921 by Wakman and Joffe.

Chemolithotroph: uses inorganic e^- donors (e.g. Fe^{2+} or S^{2-} or both);

Facultative anaerobe: uses molecular oxygen, ferric iron, or sulfur as electron acceptor;

Obligate autotroph: fixes CO_2 via the Calvin–Benson– Bassham cycle in carboxysomes;

Facultative diazotroph

Acidity and alkalinity: Ecology – Microbial diversity

Photoautotrophy: Most important mechanism of primary production in acidic ecosystems, mainly for eukaryotic microalgae.

Green algae *Chlamydomonas spp.* isolated from Rio Tinto (Spain)

Aguilera (2013) Life 3,363-374

Acidity and alkalinity: Ecology – Microbial diversity

Facultative autotrophs: some organisms are able to switch to C assimilation when this becomes available and if there's enough solar energy (e.g. *Galdieria sulphuraria*)

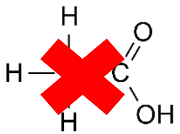
Galdieria sulphuraria **(Reykjavik)**

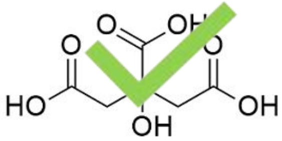
http://www.nationalgeographic.com National Geographic.

Acidity and alkalinity: Ecology – Microbial diversity

<u>*HETEROTROPHIC ACIDOPHILES*</u>

Large number of acidophilic bacteria and archaea known to use organic compounds (i.e. citric acid, glutamic acid) as energy sources.





Some are also able to supplement energy budgets by oxidizing inorganic substrates (Fe^{2+} or S^{2-}) like ***Ferromicrobium (Fm.) acidiphilum.***

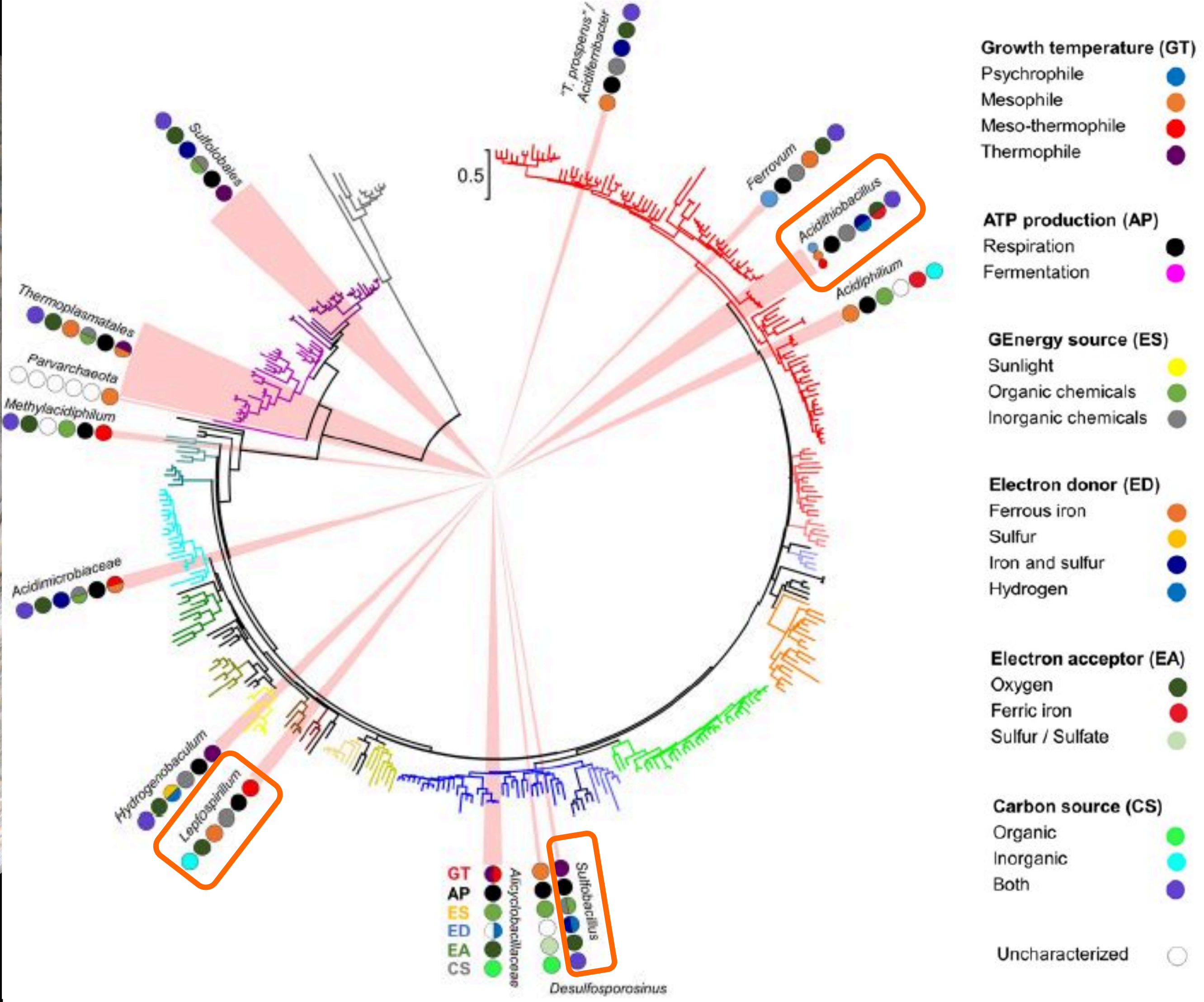
Acidilobus aceticus, grows anaerobically on starch to form acetate as the main metabolic product.

Acidity and alkalinity: Ecology – Microbial diversity

Acidophiles

- Ferric iron respiration
  - Most of the acidophiles
    - *Acidothiobacillus ferrooxidans* → Obligate autotrophs
    - *Acidiphilium*, *Acidocella*, *Acidobacterium spp.* — Obligate heterotrophs
- Sulfur respiration
  - Not uncommon
    - *Acidianus*, *Stygiolobus* — Facultative anaerobes
    - *Thermoplasma* → Facultative anaerobes that couple oxidation of C_{org} to reduction of S^0
    - *Sulfurisphaera* → Obligate anaerobes
- Sulfate reducing bacteria/archaea
  - Evidence of sulfido-genes in *Desulfosporosinus-like isolate*
- ~~Methanogenesis~~
- Fermentation
  - Only exception
    - *Acidianus aceticus*

Acidity and alkalinity: Metabolic diversity of acidophiles



<u>Acidophiles are often</u>

POLI – EXTREMOPHILES

Specialized

Leptospirillum

A. ferrooxidans

Sulfobacillus spp.

Generalist

ALKALIPHILES MICROBIAL DIVERSITY

Acidity and alkalinity: Ecology – Microbial diversity

- Alkaliphiles
  - Aerobic
    - Often coexists with neutrophilic microorganisms
      - *Bacillus, Pseudomonas, Bogoriella, Halomonas, Alkalibacillus*
      - Eukaryotes like *Dietzia, Vagococcus, Paenibacillus, Marinobacter, Roseinatrobacter, Alkalimonas, Rhodobaca*
    - Methanotrophs low salt-tolerant alkaliphiles
      - *Methylomicrobium*

Acidity and alkalinity: Ecology – Microbial diversity

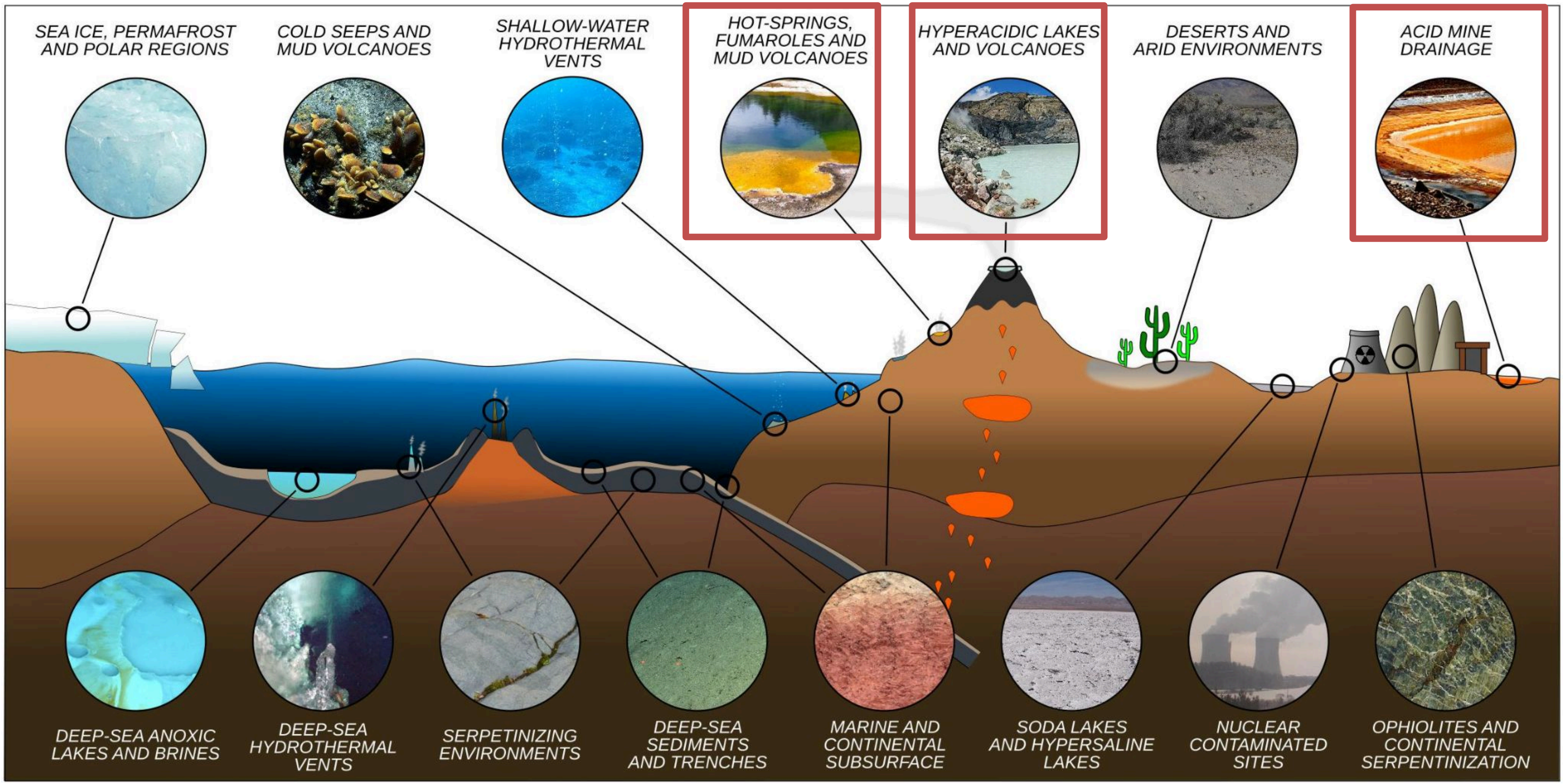
- Alkaliphiles
  - Anaerobic
    - Sulfate-reducing bacterium
      - *Desulfonatrovibrio hydrogenovorans, Desulfonatrum lacustre, Desulfonatrum cooperativum*
    - Ammonium oxidizing bacteria
      - *Nitrosomonas halophila*
    - Sulfur oxidizing bacteria
      - *Gammaproteobacteria-Thioalkalimicrobium, Thioalkalivibrio, Thioalkalispira*
    - Methanogens
      - Methylomicrobium-Methylobacter
    - Fermentation
      - Dominated by haloalkaliphilic representatives of Clostridia (i.e. *Anoxynatronum, Anaero virgula, Alkaliphilus, Natranaerobius, Natranaerobaculum*)
      - Heterotrophic anaerobic fermentative haloalkaliphiles actively fix nitrogen in soda lakes and soda soils

Acidity and alkalinity: Ecology – Environments

WHERE CAN WE FIND ACIDOPHILES, HYPER-ACIDOPHILES AND ALKALIPHILES?

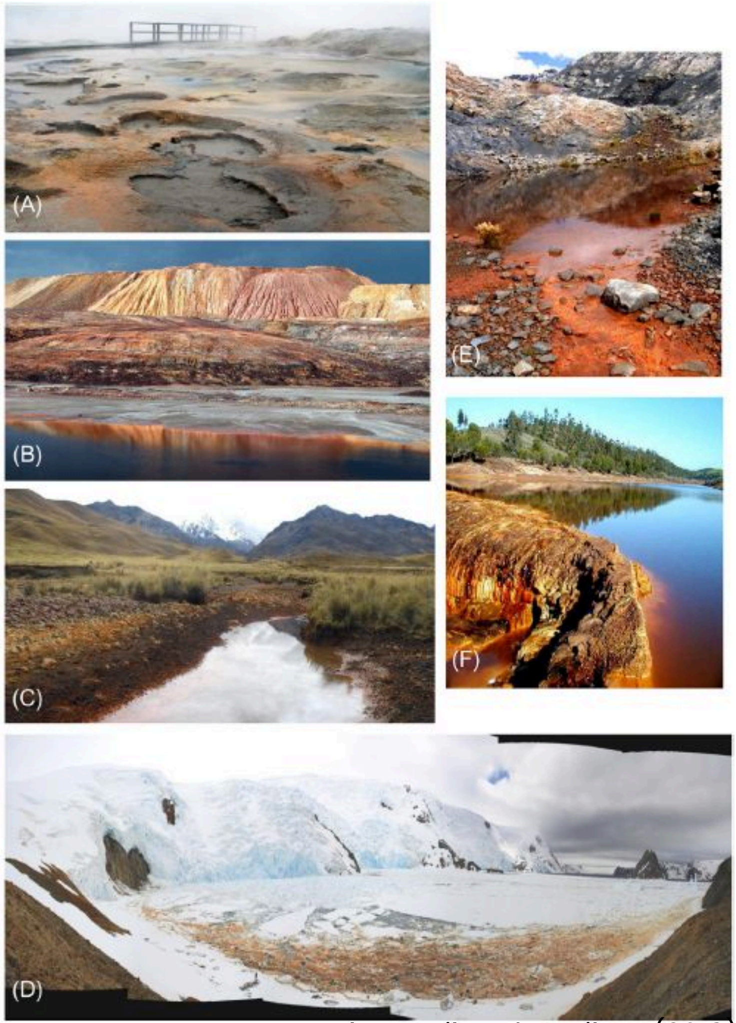
Acidity and alkalinity: Ecology – Environments

ACID AND HYPERACID ENVIRONMENTS



Merino et al. (2019) Frontiers Microbilogy 10: 1–25

Acidity and alkalinity: Ecology – Environments



Gonzalez-Toril and Aguilera (2019)

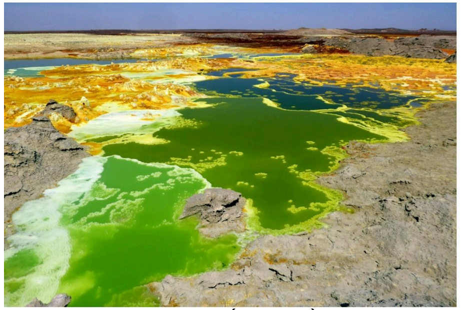
Acidic habitats have two major origins:

- ✔ Natural: volcanic and magmatic activities (hydrothermal vents, hyperacidic lakes, fumaroles/solfataras, mud volcanoes)
- ✔ Anthropogenic: metal and coal mining

(A) Geothermal area in Reykjanes Peninsula (SW, Iceland)
(B) Acidic mining drainage area in Rio Tinto (SW, Spain)
(C) Acidic rock drainage area in Huascaran National Park (Peru),
(D) Acidic rock drainage area in Almirantazgo Bay (Shetland Islands, Antarctica)
(E) acidic rock drainage area in Pachacoto river (Huascaran National Park, Peru)
(F) Rio Tinto at Nerva area (Spain).

Acidity and alkalinity: Ecology – Environments

Frying Pan Hot Spring (Yellowston Park, USA). Johnson (2009)



Dallol dome hot springs (Ethiopia) Belilla et al. (2019)

Yellowstone mud volcanoe(USA)

Geothermal features: Hotsprings, fumaroles, solfataras, and mud volcanoes

- ✔ **Hot springs:** spring with water at temperatures substantially higher than the air temperature of the surrounding region due to the heat generated by shallow intrusions of magma in volcanic areas.
- ✔ **Fumaroles:** vent in the Earth's surface from which steam and volcanic gases are emitted (CO_2, SO_2 and H_2S). The mixture of steam and gas is erupted from vents and fissures in the ground surrounding rock forming viscous pools of bubbling mud (mud volcanoes).
- ✔ **Solfataras:** a type of fumarole in which sulfur gases are the dominant constituent along with hot water vapour.

Pozzuoli Solfatara (Di Donar Reiskoffer, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=238345

Hyperacidic crater lake at Kawah Ijen (Java, Indonesia)

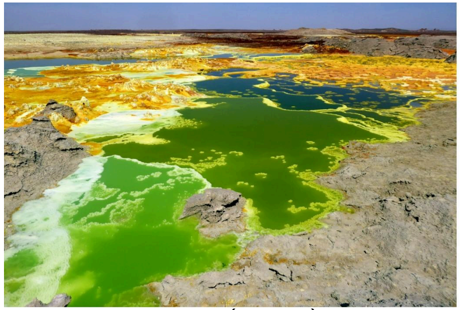
Acidity and alkalinity: Ecology – Environments

Frying Pan Hot Spring (Yellowston Park, USA). Johnson (2009)

Geothermal features: Hotsprings, fumaroles, solfataras, and mud volcanoes

S^0 can form in geothermal areas through the condensation of SO_2 and H_2S according to this reaction:

$$\mathbf{SO_2 + 2\,H_2S \rightleftharpoons 2\,H_2O + 3\,S^0}$$



Dallol dome hot springs (Ethiopia) Belilla et al. (2019)

Acidophilic bacteria and archaea then oxidize S^0 to produce H_2SO_4

$$\mathbf{S^0 + H_2O + 1.5\,O_2 \rightleftharpoons 2\,H_2SO_4}$$

$$\mathbf{H_2SO_4 \rightleftharpoons HSO_4^- + H^+ \rightleftharpoons SO_4^{2-} + H^+}$$

Yellowstone mud volcanoe(USA)

Pozzuoli Solfatara (Di Donar Reiskoffer, CC BY-SA 3.0,https://commons.wikimedia.org/w/index.php?curid=238345

Hyperacidic crater lake at Kawah Ijen (Java, Indonesia)

Acidity and alkalinity: Ecology – Environments

Kupferschiefer deposits (central Europe)

Sao Domingo mine (Portugal)

Gossans

Acid production is often limited by the physical nature of the **unweathered rock**, restricting its exposure to both oxygen and water

Acidity and alkalinity: Ecology – Environments

The oxidative dissolution of pyrite by acidophilic bacteria and its role in generating acidic, metal rich pollution, such as acid mine drainage waters, can be seen through the equation:

$$FeS_2 + 3.75O_2 + 0.5H_2O \rightleftharpoons Fe^{3+} + 2SO_4^{2-} + H^+$$

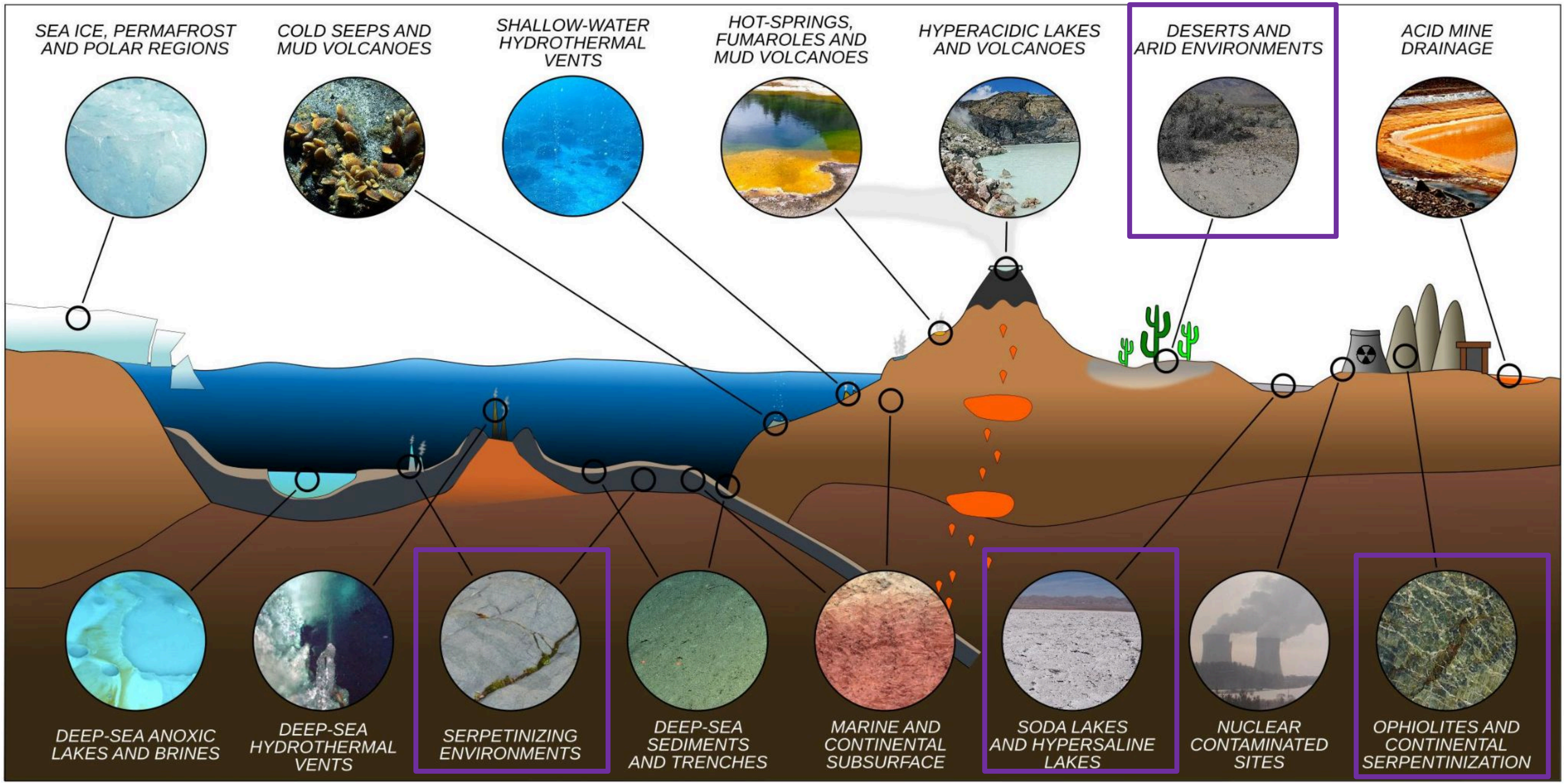
✔ Net acid-generating reaction.

the Rio Tinto (SW Spain) maintains a pH of between ~ 2.2 and 2.8 throughout its 100 km length due to this reaction.

General view of Rio Tinto (Spain). Aguilera (2013)

Acidity and alkalinity: Ecology – Environments

ALKALINE ENVIRONMENTS



Merino et al. (2019) Frontiers Microbilogy 10: 1–25

Acidity and alkalinity: Ecology – Environments

Lake Magadi (Kenya)

Wadi el Natrun (Egypt)

<u>Stable alkaline environments:</u>

Climatic + geological + geographical conditions

- pH > 10
- Two types: low Ca^{2+} and high Ca^{2+}

Mono lake(USA)

Soda lake of Kulunda Steppe (Russia)

Acidity and alkalinity: Ecology – Environments


Lake Magadi (Kenya)


Wadi el Natrun (Egypt)

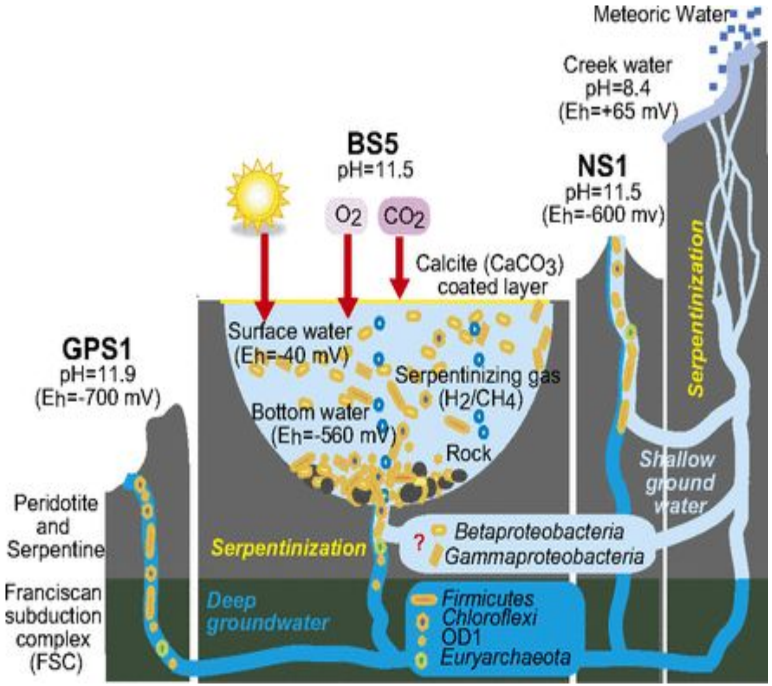
Stable alkaline environments:

Low Ca^{2+} soda lakes and deserts:

- ✔ High amount of $NaCO_3$ due to evaporative concentration
- ✔ In the absence of Ca and Mg, groundwater enriched with HCO_3^- is present
- ✔ Evaporative concentration of ions leads to a shift in the $CO_2/HCO_3^-/CO_3^{2-}$ equilibrium
- ✔ The concentration of other salts, like NaCl, gives rise to environments both saline and alkaline


Soda lake of Kulunda Steppe (Russia)

Acidity and alkalinity: Ecology – Environments



Suzuki et al. (2013)

Stable alkaline environments:

High Ca^{2+} alkaline environments (pH ≥11):

Developed in areas where low temperature weathering of ultramafic (Olivine, Pyroxenes and Clinopyroxenes) minerals is possible .

Olivines (Ol) and pyroxenes (Px) decompose when exposed to waters enriched with CO_2 releasing Ca^{2+} and OH^- into the solution.

$$2Mg_2SiO_4 + 3H_2O \rightleftharpoons Mg_3Si_2O_5(OH)_4 + Mg(OH)_2$$

$$2CaMgSi_2O_6 + 5MgSiO_3 + H_2O \leftrightharpoons Ca_2Mg_5Si_8O_{22}(OH)_2 + Mg_2SiO_4$$

Mg^{2+} and Fe^{2+} are removed by precipitation of the mineral phases: Brucite, Magnesite or Dolomite, while Ca^{2+} remains in the solution.

In these type of environments («The Cedars» subduction zone) Suzuki et al. (2014) isolated Betaproteobacteria *Serpentinomonas spp.*

Acidity and alkalinity: Ecology – Environments


Octopus Spring (Yellowstone Park, USA)

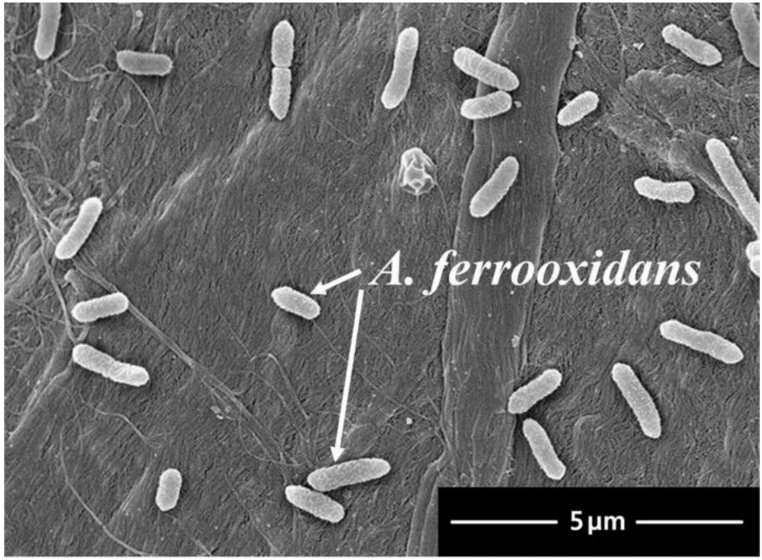
<u>Transient alkaline environments:</u>
pH values rarely over 9.5

- ✔ Soil microhabitats due to ammonification and sulfate reduction
- ✔ Alkaline hot springs in volcanic areas generated through silicate decomposition

Acidity and alkalinity: Taxonomy of acidophiles

Acidithiobacillus ferrooxidans

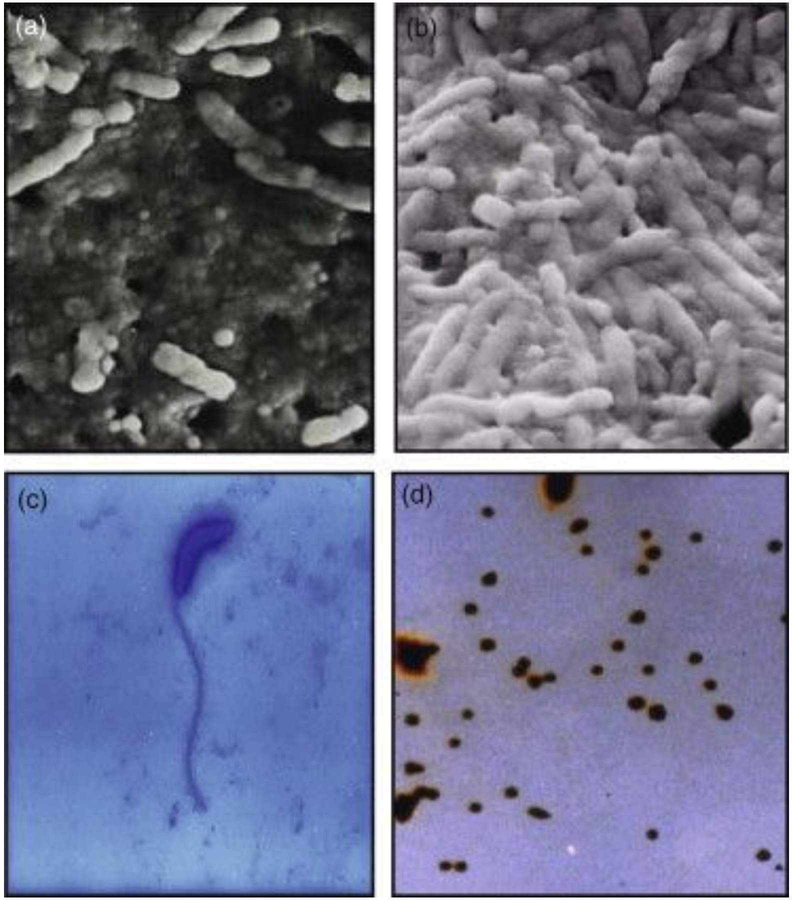
- *A. ferrooxidans* is a **Gram negative** rod shaped bacterium that is commonly found in **deep caves** or **acid mine drainage**, such as coal waste.
- Optimal **pH level of 1.5 – 2.5** where they convert insoluble metals to their soluble state. Even low concentrations (ppm) of these metallic ions would be extremely toxic to other bacteria.
- A. ferrooxidans is a **chemolithoautotrophic** bacterium which can use many different electron donors to support growth.
- In **aerobic conditions**, electron donors may include **ferrous ions or sulfur compounds** which are oxidized into ferric iron and sulfuric acid, respectively, yielding high energy. However, during **anaerobic conditions** **ferric ions** can replace oxygen as the electron acceptor with multiple substrates donating an electron.
- *A. ferrooxidans* can fix atmospheric **CO_2** as a **carbon source** essential for biomass. Nitrogen is a common limiting nutrient scarce in the environment; however, A. ferrooxidans can fix atmospheric nitrogen into ammonia (NH_3) essential for nucleotides and amino acids.



Acidity and alkalinity: Taxonomy of acidophiles

Leptospirillum ferroxidans

- *Leptospirillum* is a genus of **iron-oxidizing bacteria** which play an important role in industrial bioleaching (the conversion of metals to a soluble form) and biooxidation (the extraction of metals).
- They are **obligate aerobes** (require oxygen gas).
- Primary iron-oxidizers in industrial continuous-flow biooxidation tanks.
- Metabolically they are **strictly chemolithoautotrophic**, fixing carbon using ferrous iron as their electron donor and oxygen as the electron acceptor. Because of this, they are **some of the most metabolically-restricted** organisms known.
- *Leptospirilla* are also important contributors to the **acid mine drainage process**.

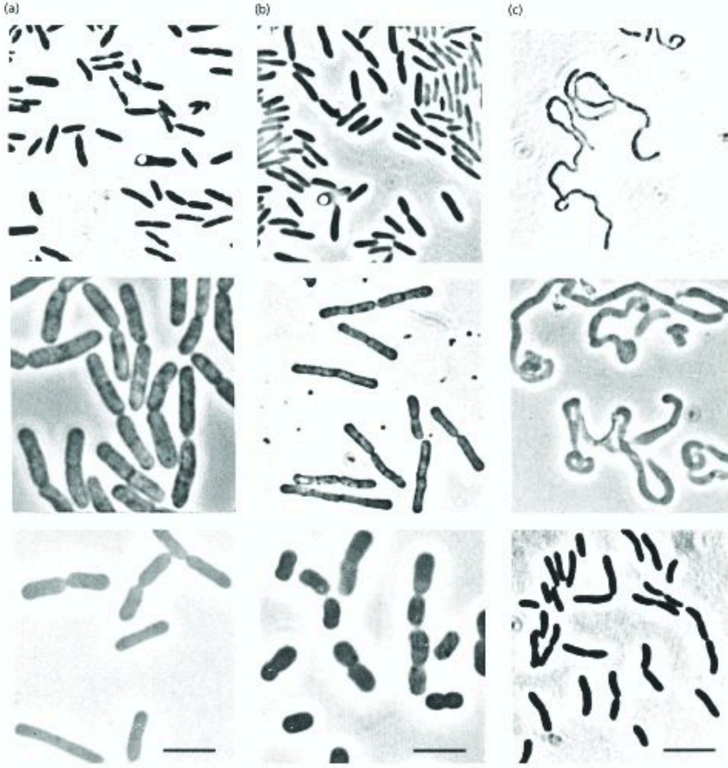


C.A. Jerez, in Comprehensive Biotechnology (Second Edition), 2011

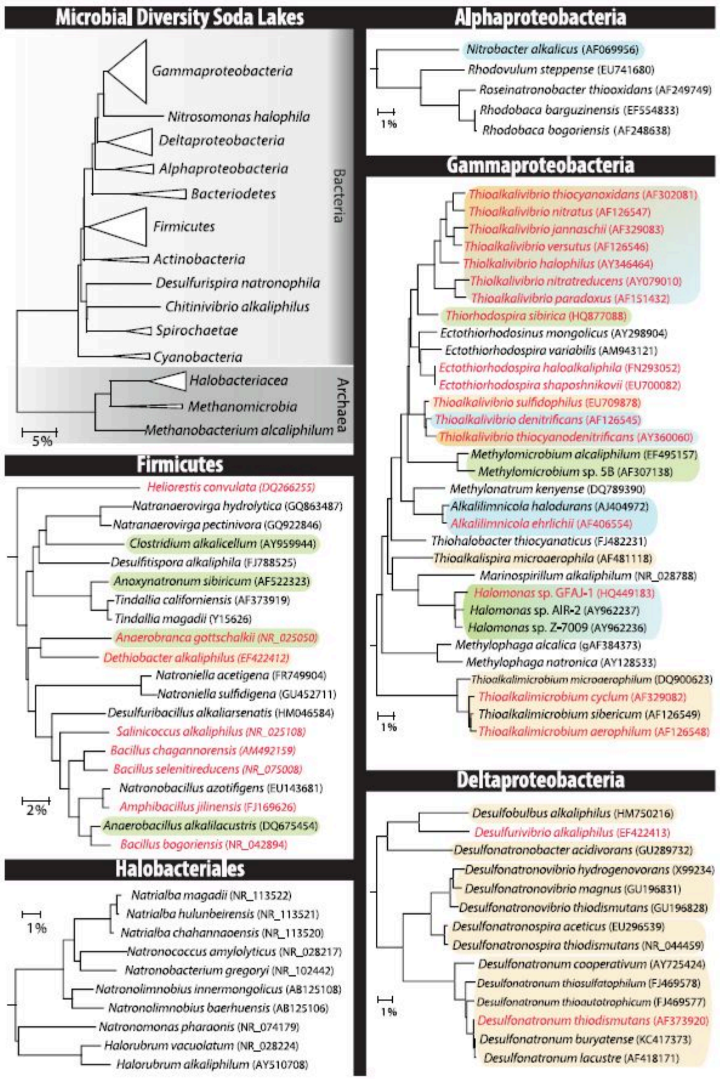
Acidity and alkalinity: Taxonomy of acidophiles

Sulfobacillus thermosulfidooxidans

- *Sulfobacillus thermosulfidooxidans* is a species of bacteria of the genus Sulfobacillus.
- **S. thermosulfidooxidans** is acidophilic and **moderately thermophilic**;
- All prefer environments around **pH 2.0** with optimal growth **temperatures ranging from 45 °C to 55 °C**;
- *S. thermosulfidooxidans* **is an iron- and sulfur-oxidizer,** capable of oxidation of elemental sulfur, tetrathionate, and sulfides;
- **Facultative chemolithotroph;**
- Also capable of **chemoorganoheterotrophic** growth;
- Widely distributed in both natural and artificial acidic environments, including hot springs and acid mine drainage;
- Used in biohydrometallurgical (biomining) approaches for the recovery of precious and non-ferrous metals.



Acidity and alkalinity: Taxonomy of alkaliphiles



Salt concentration in the sedimentary pore water of **soda lakes** has a **strong influence** on the in situ microbial **community composition** and **negatively affects** the **diversity**

Phylogenetic tree of identified bacteria and archaea in soda lakes (Sorokin, 2014)

Acidity and alkalinity: Taxonomy of alkaliphiles

Serpentinomonas gen. nov.

- *Serpentinomonas* strains are **obligate alkaliphilic** and **facultative hydrogen-utilizing** bacteria.
- Serpentinomonas strains utilize **$CaCO_3$** for carbon fixation, coupled with **hydrogen oxidation** at high pH.
- **Ca^{2+}** released in the alkaline water appears to be a great **carbon-trapping** mechanism for the Serpentinomonas microbes.
- Serpentinomonas strains have **diverse metabolic abilities** in terms of organic carbon compounds and electron acceptor utilization.
- The most used **electron acceptor** is **oxygen**, so they mostly rely on Aerobic respiration.
- Some strains of Serpentinomonas can grow by fermenting sugars, such as glucose.

Table 2 | Summary of physiological characteristics of strains A1, B1 and H1.

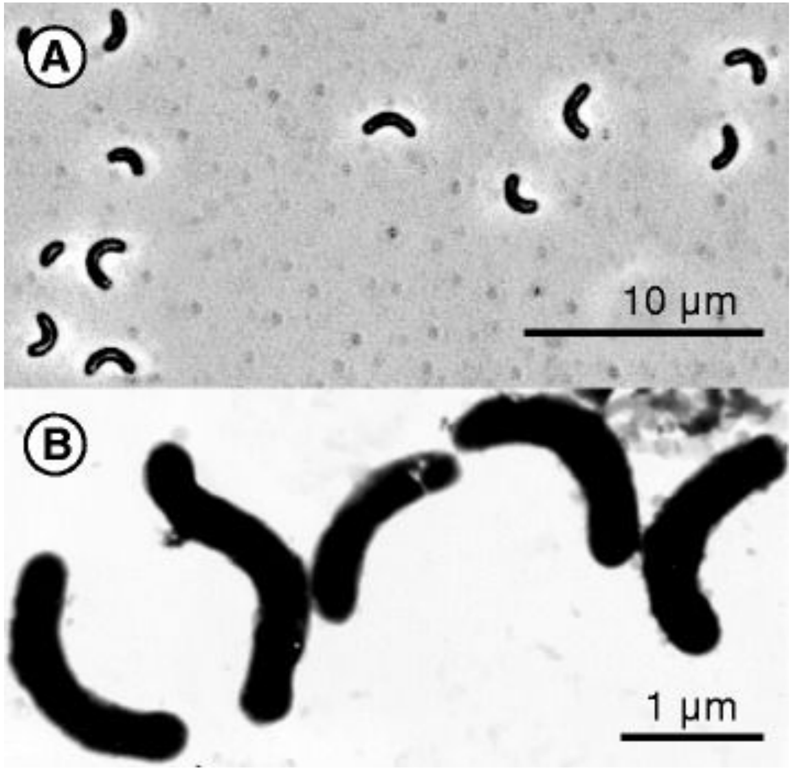
	Strain A1	Strain B1	Strain H1
Temperature range (°C)	18–37	18–37	18–37
Optimum temperature	26–30	30	30
pH range	10.0–11.5	9.5–12.5	9–12
Optimum pH	11	11	11
NaCl range ($g\,l^{-1}$)	0–0.5	0–0.5	0–0.5
Optimum NaCl	0	0	0
Flagella	Polar	Polar	Polar
Autotrophic growth			
H_2/$CaCO_3$/Oxygen	++	++	++
Mixotrophic growth			
Acetate	+++	+++	+++
Lactate	+++	+++	+++
Glucose	+	+++	+++
Cyclohexane	+++	±	−
Electron acceptor utilization			
Oxygen	+++	+++	+++
Nitrate	−	+++	+++
Sulphate	−	−	−
Thiosulphate	+++	−	−
Fermentation			
Glucose	−	+++	+++

+, positive; −, negative.

Acidity and alkalinity: Taxonomy of alkaliphiles

Desulfurivibrio alkaliphilus

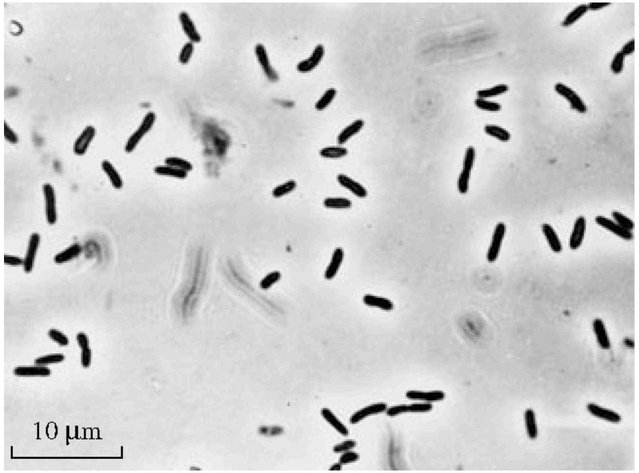
- *Desulfurivibrio alkaliphilus* are strictly anaerobic sulfidogenic haloalkaliphiles.
- The cells are **Gram-negative**, **non-motile, curved rods** that do not form spores.
- Members of this species are capable of chemolithoautotrophic growth through the disproportionation of elemental sulfur under alkaline conditions without iron oxides, which are normally required by neutrophilic sulfur disproportionators.
- Desulfurivibrio alkaliphilus **fixes inorganic carbon** thought the Acetyl-coA pathway.
- They can use H_2 as the electron donor and thiosulfate, elemental sulfur, polysulfide and nitrate as the electron acceptors



Acidity and alkalinity: Taxonomy of alkaliphiles

Halomonas campisalis

- An haloalkilophilic bacterium isolated from sediment samples taken from the salt plain of Alkali lake (USA).
- Members of this species have **rod-shaped** cells, and can use as **electron acceptors**: **oxygen**, **nitrate** and **nitrite** (capable of doing **denitrification**) and a variety of electron donors.
- Carbon sources include:Acetate, Lactate, Glycerol, Ethanol and Methanol.
- *Halomonas campisalis* is unable to grow fermentatively.
- They can grow at a wide range of temperature, ranging from **4 to 50 ºC**, with **optimal growth at 30º C.**
- Due to its denitrification ability, broad carbon utilization range and high salinity tolerance, they can be used for the treatment of saline, alkaline waste.



Acidophiles and alkaliphiles: Biotech Applications

Biotechnological potential of acidophiles and extremely acidophiles

Sulfate reduction for remediation of streams contaminated by mining or metallurgical industries

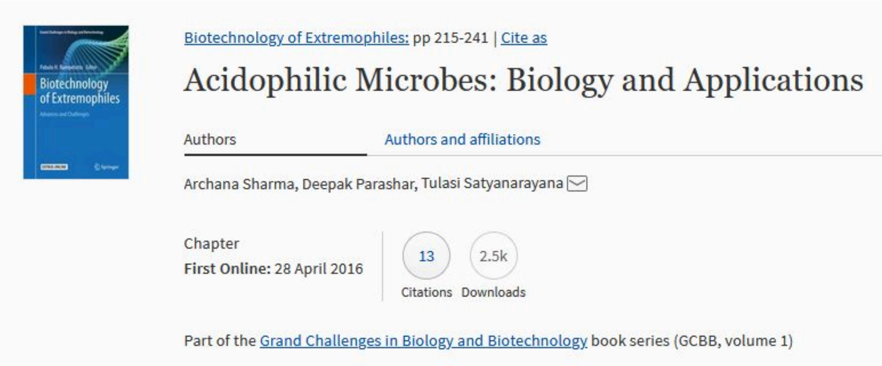
Known acidophilic sulfate reducing bacteria that can be used:
- *Thermodesulfobium narugense*
- *Desulfosporosinus acidiphilus*
- *Desulfosporosinus acidurans*

Sulfur reduction for recovery of acid mine drainages

Acidophilic sulfur reducing bacteria used:
- *A. ferrooxidans* (pH 1.8)
- *Acidilobus sulfurireducens* (pH 2)
- *Acidianus infernus* (pH 1.5)

Main advantage sulfur reducers can generally reduce elemental sulfur at pH values lower than the above mentioned sulfate reducers

Remediation of metal laden streams in metallurgical processes



Biotechnology of Extremophiles: pp 215-241 | Cite as

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Chapter

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Acidophiles and alkaliphiles: Biotech Applications

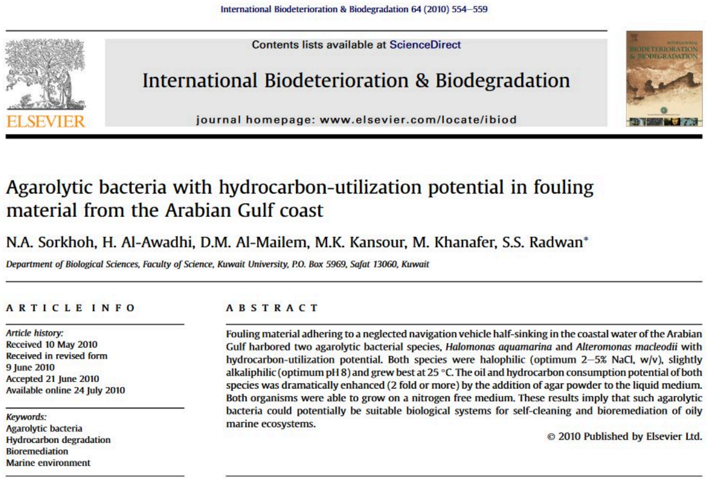
Biotechnological potential of alkaliphiles

Sr. No.	Alkaliphile	Isolation Site	Product/Application	Reference
1	*Bacillus* sp.	Alkaline soda Lake, Ethiopia	Xylanase	Gessesse and Mamo (1999)
2	*Exiguobacterium oxidotolerans*	Fish processing plant, Hokkaido, Japan	Catalase	Yumoto et al. (2004)
3	*Streptomyces tanashiensis*	Loktak lake of Manipur, India	Antimicrobial activity	Singh et al. (2009)
4	*Halomonas* sp.	Wheat straw black liquor	CMCase, xylanase, lipase, amylase, and pullulanase	Yang et al. (2010)
5	*Streptomyces aburaviensis*	Saline desert of Kutch, India	Antimicrobial activity	Thumar et al. (2010)
6	*Acinetobacter* sp.	Oil Spilling sites, Gujarat India	Synthetic chemistry	Ahmed et al. (2010)
7	*Chitinophaga pinensis*	Cold desert, Antarctic (metagenomic library of soil)	Lipases/esterases	Hu et al. (2012)
8	*Bacillus cereus*	Bani Salama Lake, Wadi El-Natron, Egypt	Mannanase	El-Sharouny et al. (2015)
9	*Streptomyces* sp.	Arid soil, Boussaada, Algeria	Antifungal	Souagui et al. (2015)
10	*Bacillus, Corynebacterium, Micrococcus,* and *Actinomycetes, Flavobacterium*	Mangrove ecosystems, Goa, India	Biodegradation of aromatic hydrocarbons	Desai Gaokar (2015)
11	*Bacillus marmarensis*	–	Biorefining of cellulose	Wernick et al. (2016)
12	*Bacillus infantis* SKS1	Garden Soil, India	Proteases	Saggu and Mishra (2017)
13	*Alkaliphilus namsaraevii*	Steppe soda lake, Transbaikal Region, Russia	Reducing activity against iron and sulfur in alkaline pH	Zakharyuk et al. (2017)

CMCase, carboxymethylcellulase.

Kanekar et al. (2015) Biotechnological potential of alkilophilic microorganisms pp. 249-279

Halomonas aquamarina and ***Alteromonas macleodii***, suitable as biological systems for bioremediation of oily marine ecosystems.


International Biodeterioration & Biodegradation 64 (2010) 554–559

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ELSEVIER

Agarolytic bacteria with hydrocarbon-utilization potential in fouling material from the Arabian Gulf coast

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Agarolytic bacteria
Hydrocarbon degradation
Bioremediation
Marine environment

A B S T R A C T

Fouling material adhering to a neglected navigation vehicle half-sinking in the coastal water of the Arabian Gulf harbored two agarolytic bacterial species, *Halomonas aquamarina* and *Alteromonas macleodii* with hydrocarbon-utilization potential. Both species were halophilic (optimum 2–5% NaCl, w/v), slightly alkaliphilic (optimum pH 8) and grew best at 25 °C. The oil and hydrocarbon consumption potential of both species was dramatically enhanced (2 fold or more) by the addition of agar powder to the liquid medium. Both organisms were able to grow on a nitrogen free medium. These results imply that such agarolytic bacteria could potentially be suitable biological systems for self-cleaning and bioremediation of oily marine ecosystems.

READS

Johnson, D.B. (2009) Extremophiles: Acidic Environments in *Encyclopedia of Microbiology*. https://doi.org/10.1016/B978-012373944-5.00278-9

Johnson, D.B.; Quatrini, R. (2020). Acidophile Microbiology in Space and Time. *Curr. Issues Mol. Biol.* 39: 63-76. https://doi.org/10.21775/cimb.039.063

Sorokin, D.Y., Berben, T., Melton, E.D. *et al.* (2014). Microbial diversity and biogeochemical cycling in soda lakes. *Extremophiles* 18**:** 791–809. https://doi.org/10.1007/s00792-014-0670-9

Horikoshi, K. (1999) Alkaliphiles: some applications of their products for biotechnology.
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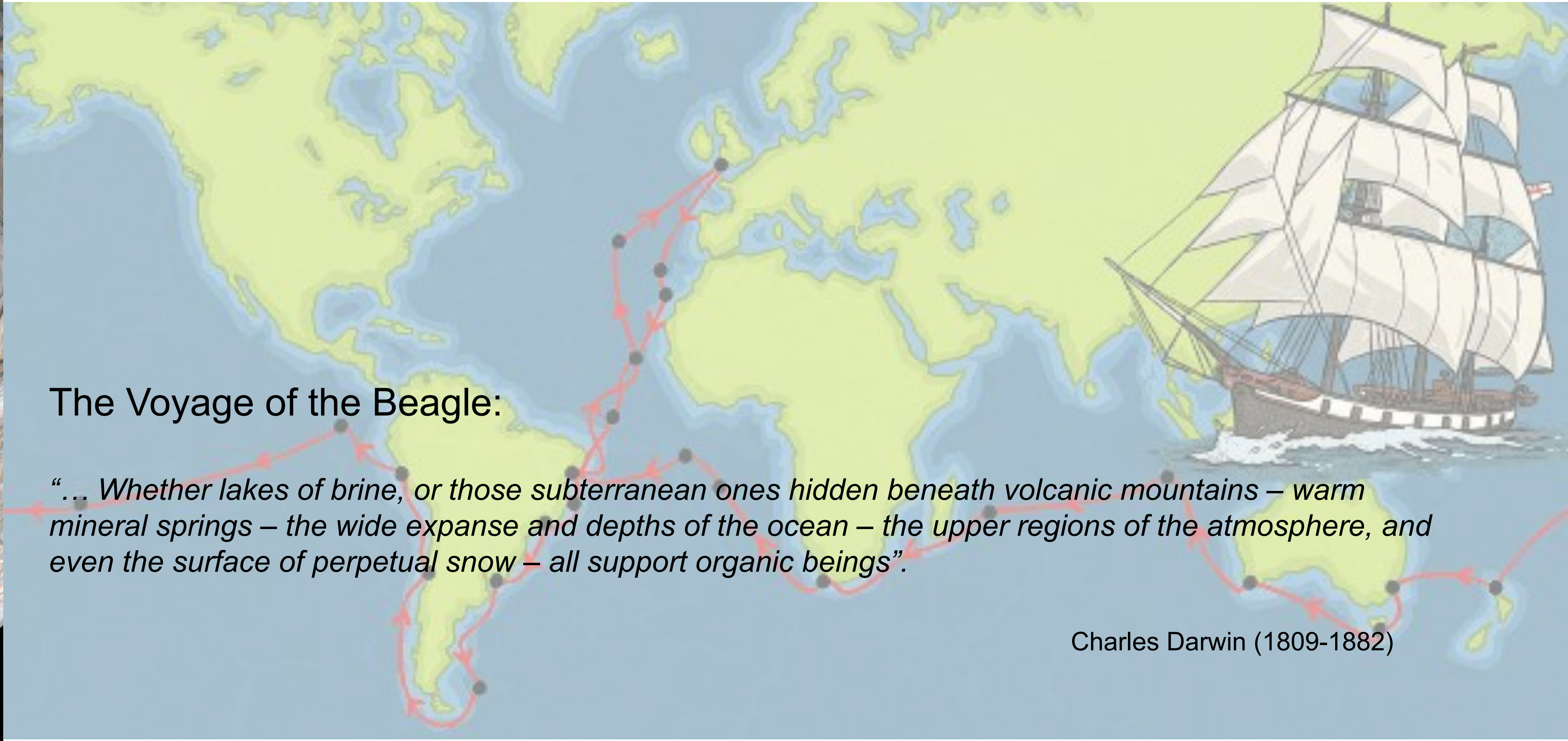
https://journals.asm.org/doi/10.1128/MMBR.63.4.735-750.1999

HALOPHILES

halo- + -phile: **salt loving**



The Voyage of the Beagle:

"… Whether lakes of brine, or those subterranean ones hidden beneath volcanic mountains – warm mineral springs – the wide expanse and depths of the ocean – the upper regions of the atmosphere, and even the surface of perpetual snow – all support organic beings".

Charles Darwin (1809-1882)

Range of life: **Salinity**

TABLE 11.1 Classification of microorganisms based on response to salt.

Class of prokaryotes with respect to salinity	Salinity conditions	Examples
Non-halophilic	<0.2 M	Bacteria thriving in freshwater
Halotolerant	Able to tolerate salt; if tolerates > 2.5 M, then considered as extremely halotolerant	*Staphylococcus* sp.
Slight halophile	0.2–0.5 M	Bacteria constituting marine habitats
Moderate halophile/ borderline extreme halophile	0.5–2.5 M/1.5–4.0 M	*Salinivibrio costicola*, *Halomonas elongate*, *Tamilnaduibactersalinus*/*Halorhodospira halophila*
Extreme halophile	2.5–5.2 M	Type species of genus *Halobacterium*, *Halobacterium salinarum*, *Halomarinaoriensis*, *Salinibacter ruber* (member of *Bacteroidetes*)

Verma Ashish et al., 2020.

Range of life: **Salinity**

High salinity (%)

Low salinity (%)

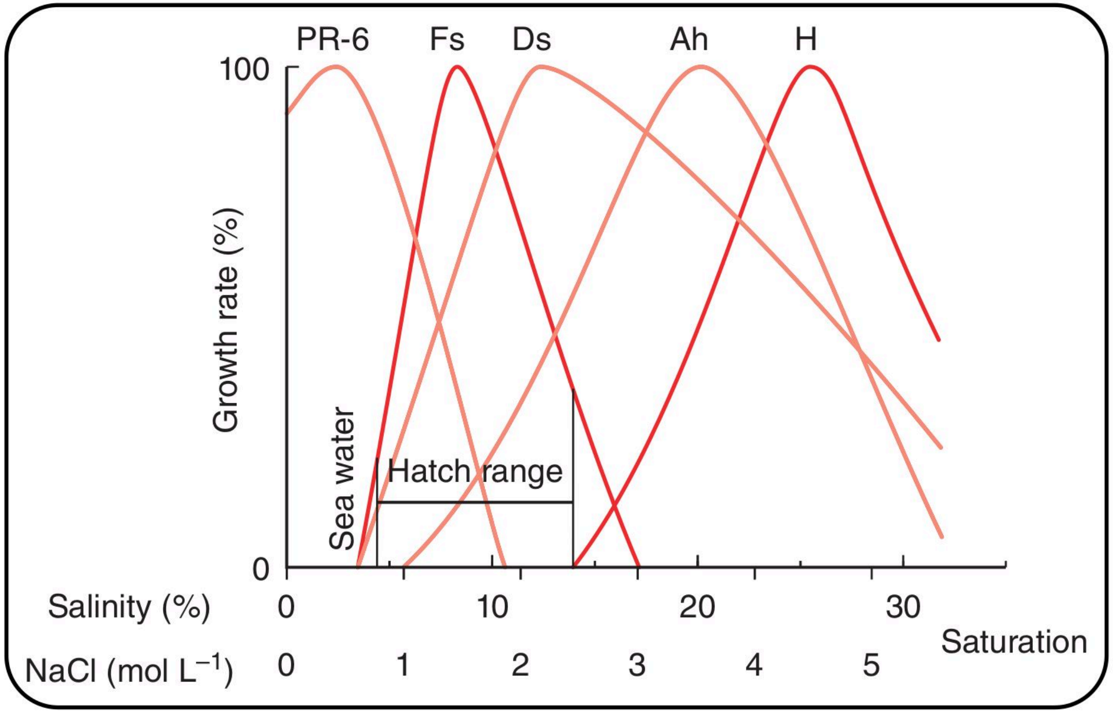
Halobacterium sp. (**H**)

Aphanothece halophytica (**Ah**)

Dunaliella salina (**Ds**)

Fabrea salina (**Fs**)

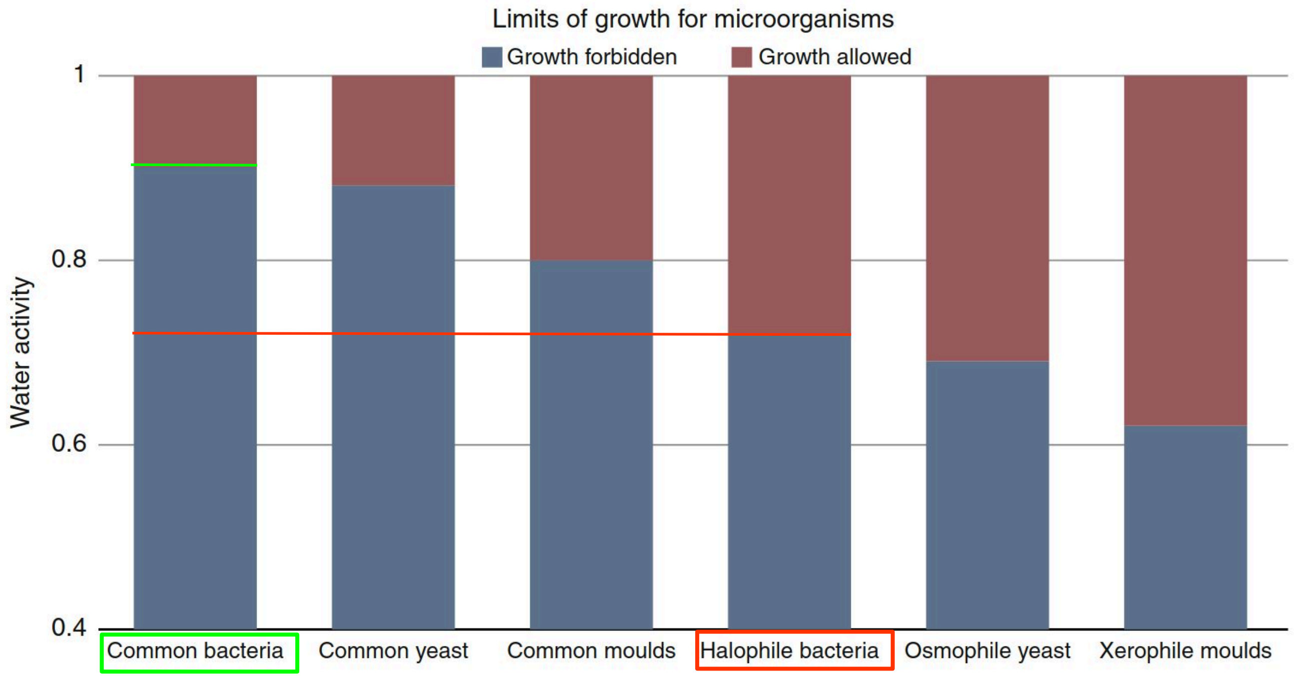
Synechococcus sp. PCC7002 (**PR-6**)



Shiladitya DasSarma and Priya DasSarma (2017)

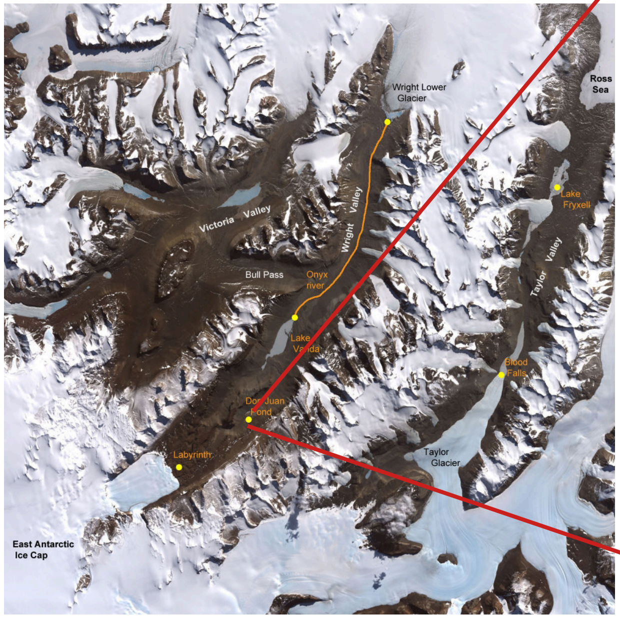
Water activity

Water activity, **aw**, is a dimensionless parameter defined as the <u>vapor pressure of water in a system (p) divided by that of pure water at the same temperature (po)</u>. It correlates with the proportion of **water available for biological or chemical reactions** and is related to the energy status of the water molecules in a given system (pure distilled water has aw=1).



Victor M. Fernández, 2011

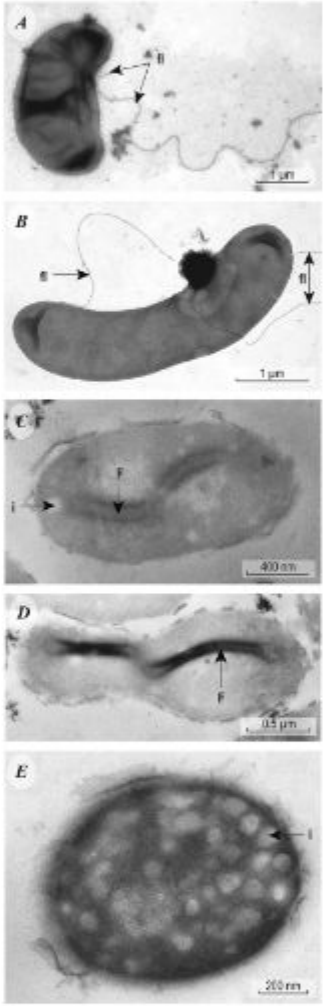
Water activity



Don Juan Pond: unfrozen lake (Antarctica)
a. $CaCl_2$- dominated brine: up to 474 g/L
b. pH: 4.6
c. Average depth: 11 cm
d. Temperatures -36°C (T_{MAX} ~ 20°C)
e. Water activity: 0.28 aw (25°C) to 0.61 aw (−50°C)

(Oren, 2013; Toner et al., 2017)

Salinity loving extremophiles.
Who are they? The _*“known”*_ extremes

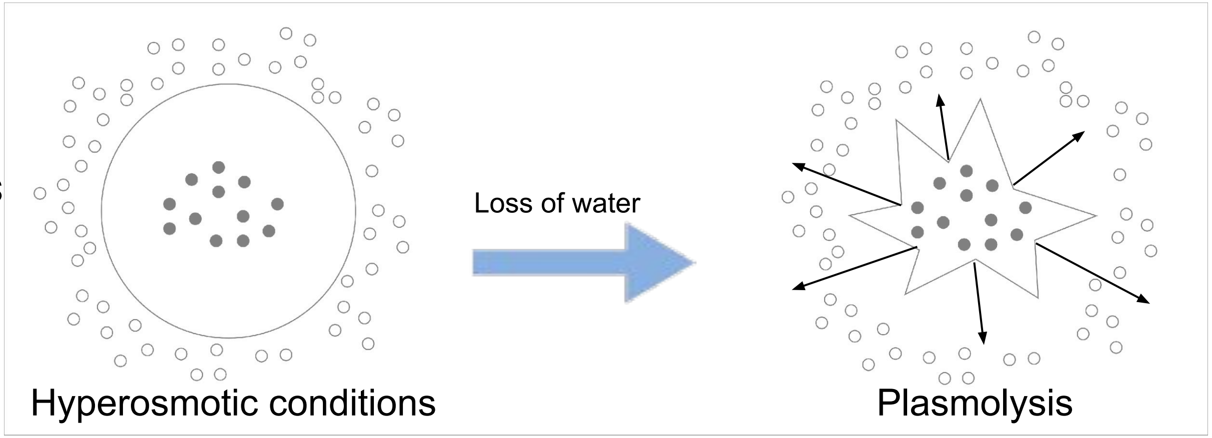


The organism that holds the record as capable of living at the highest salinity concentration is ***Halarsenatibacter silvermanii*** strain SLAS-1 growing at a **salinity optimum of 35% NaCl** isolated from the alkaline hypersaline Searles Lake (CA, USA).

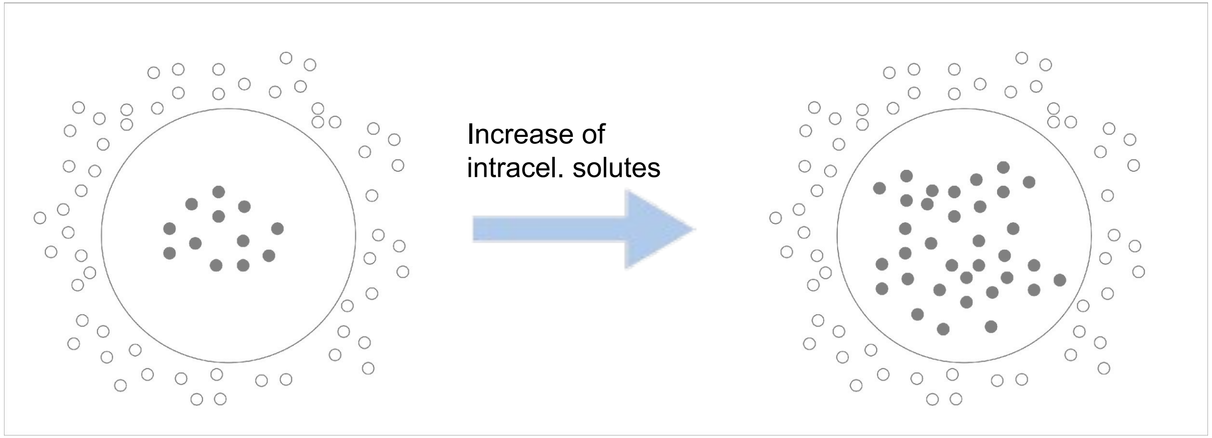
Searles Lake (CA, USA)
https://www.atlasobscura.com/places/searles-lake

Water activity and osmotic equilibrium

The survival of microorganisms in hypersaline environments requires the cells to **maintain** its **intracellular osmotic pressure**.



The regulation of lost water in the salt rich environment through the permeable biological membranes is **not energetically feasible** through active energy-dependent inward transport.



Physiological adaptation

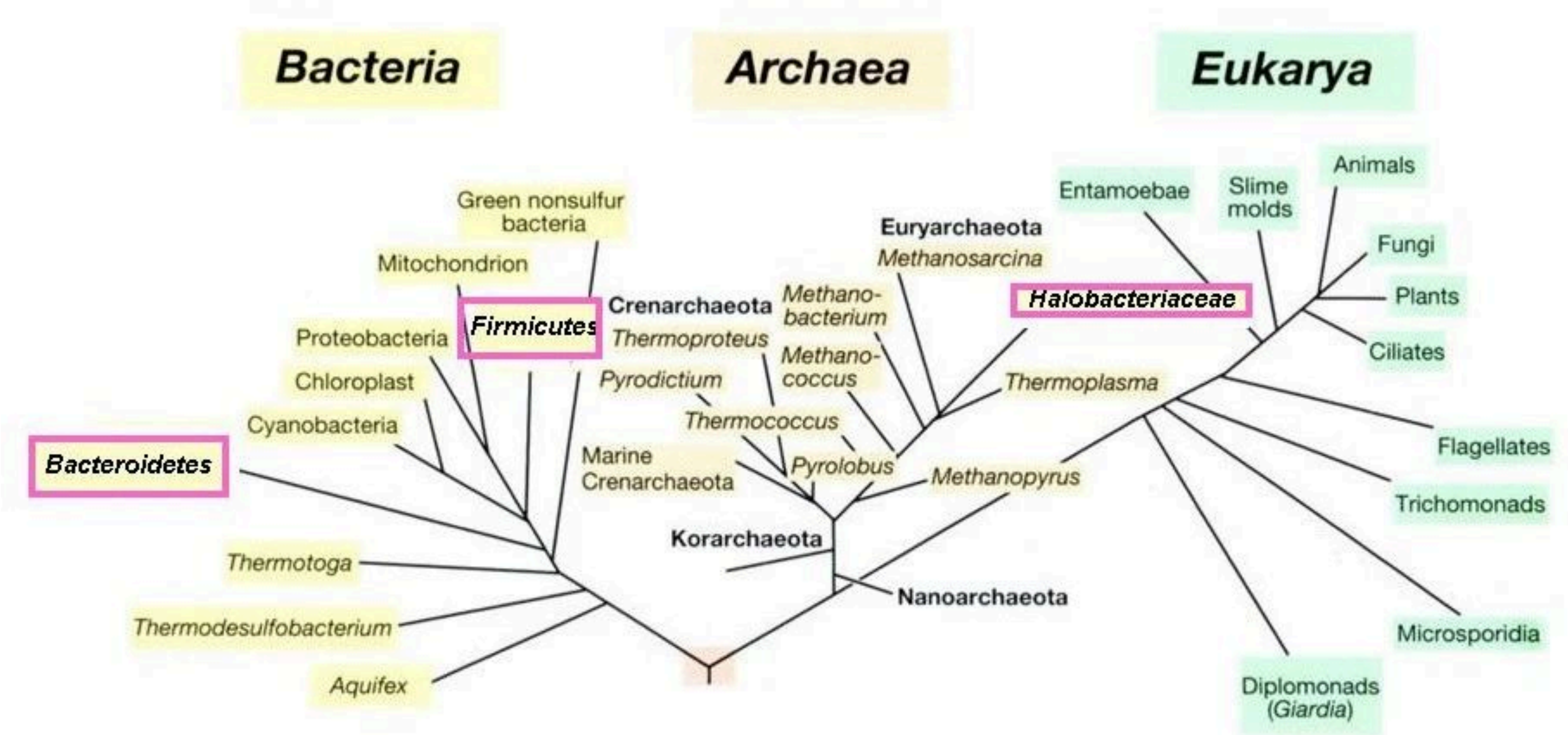
Two main **strategies**: "**HIGH** SALT-**IN**" and "**LOW** SALT-IN/SALT-**OUT**"

"SALT-**IN**": not widely used among the different phylogenetic and physiological groups of halophiles

High salt content within the cell

$\downarrow$

- Energetically **less costly to the cell** than the biosynthesis of large amounts of organic osmotic solutes;
- Involves **accumulation** of molar concentrations of $\mathbf{K^+}$ and $\mathbf{Cl^-}$ or other **inorganic solutes**;
- **Requires extensive adaptation** of the intracellular enzymatic machinery to the presence of salt.



Distribution within the phylogenetic tree of microorganisms accumulating KCl as their sole or main osmotic solute. Groups marked with purple boxes contain at least one halophilic representative (e.g. *Salinibacter ruber* within the *Bacteroidetes*). The group of the *Firmicutes* contains both microorganisms that use KCl for osmotic balance (the order *Halanaerobiales* within the low G+C branch, consisting of anaerobic fermentative organisms) and different halophilic aerobes (*Halobacillus* spp. and others) that accumulate inorganic solutes. High intracellular KCl concentrations are also found in the methanogenic halophiles, but these accumulate organic solutes as well.

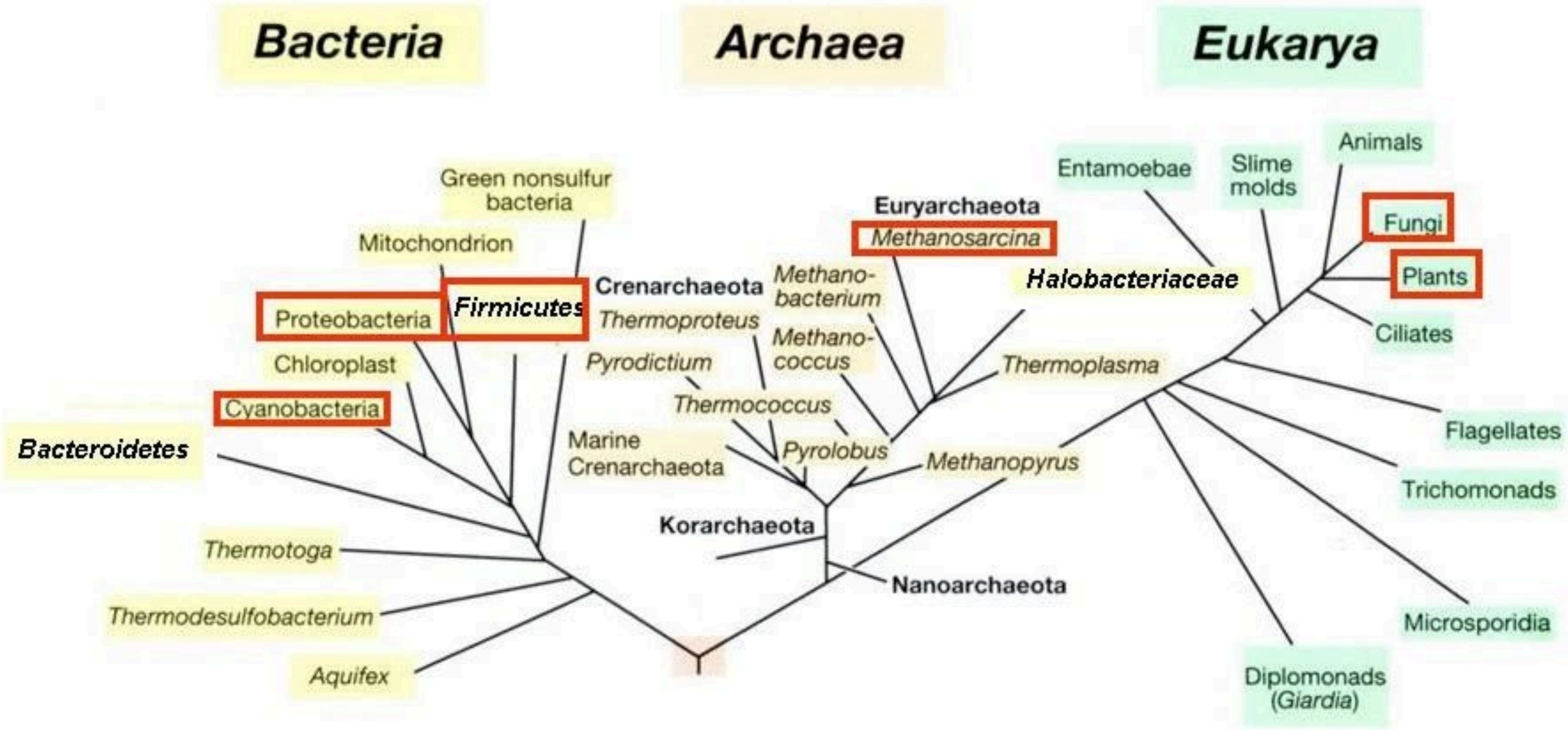
Physiological adaptation

Two main **strategies**: “**HIGH** SALT-**IN**” and “**LOW** SALT-IN/SALT-**OUT”**

“SALT-**OUT**”: most of halophilic and halotolerant Bacteria + methanogenic Archaea.

Low salt content within the cell

- **Organic compatible solutes** play a **key role** in osmotic balance;
- Cells **exclude salt from their cytoplasm** as much as possible;
- It requires few adaptations of the cells’ proteome;
- The production of massive amounts of such solutes can be **energetically costly**, thus organisms have **optimized its metabolism to minimize** the energetic cost of osmotic adaptation



Distribution within the phylogenetic tree of microorganisms accumulating organic solutes to provide osmotic balance. Groups marked with red boxes contain at least some halophilic representatives in which de novo synthesis and/or accumulation of organic solutes has been demonstrated. The group of the *Firmicutes* contains both halophilic aerobes that accumulate organic solutes and anaerobic fermentative microorganisms (the order *Halanaerobiales*) that use KCl.

Physiological adaptation: HIGH SALT-IN STRATEGY

Halobacteriales order

Pathways:

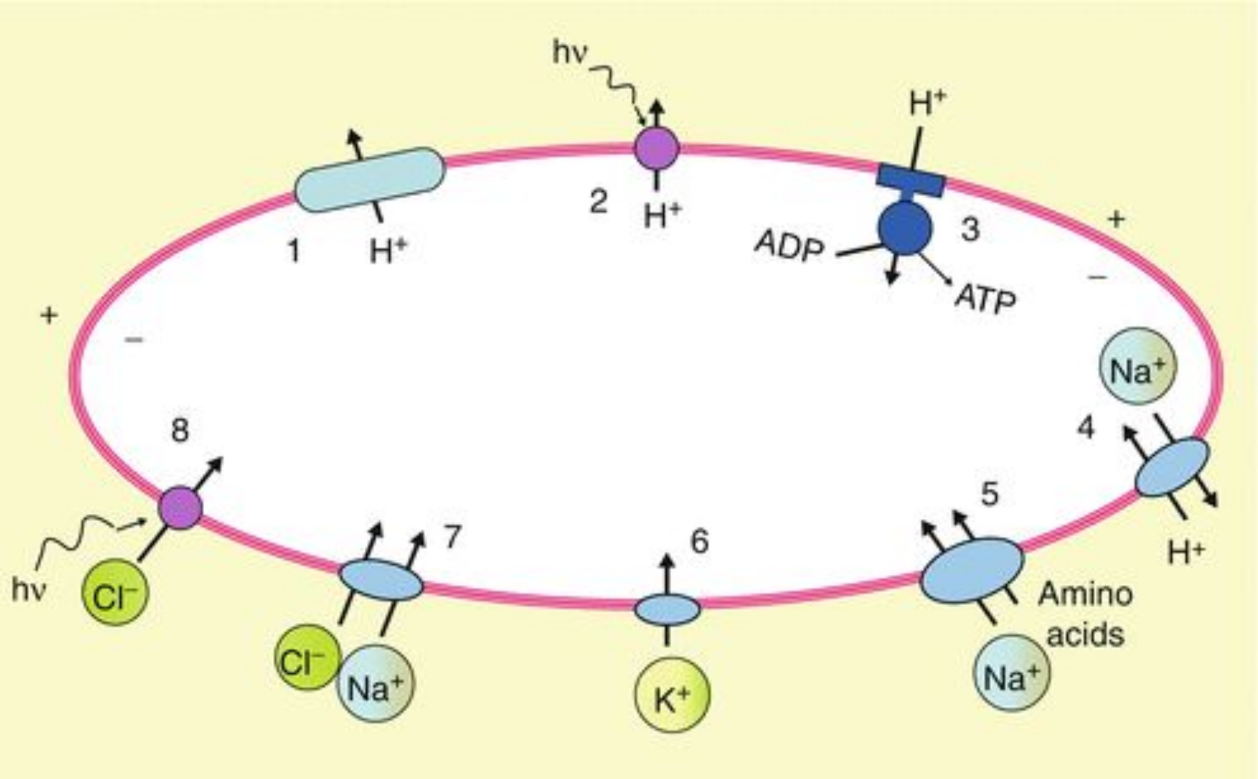
1 – 2: **Protons extrusion**

3: **ATP formation**

4 – 5: **Na^+ extrusion and syimport**

6: **K^+ accumulation**

7-8: **Cl^- pumps**



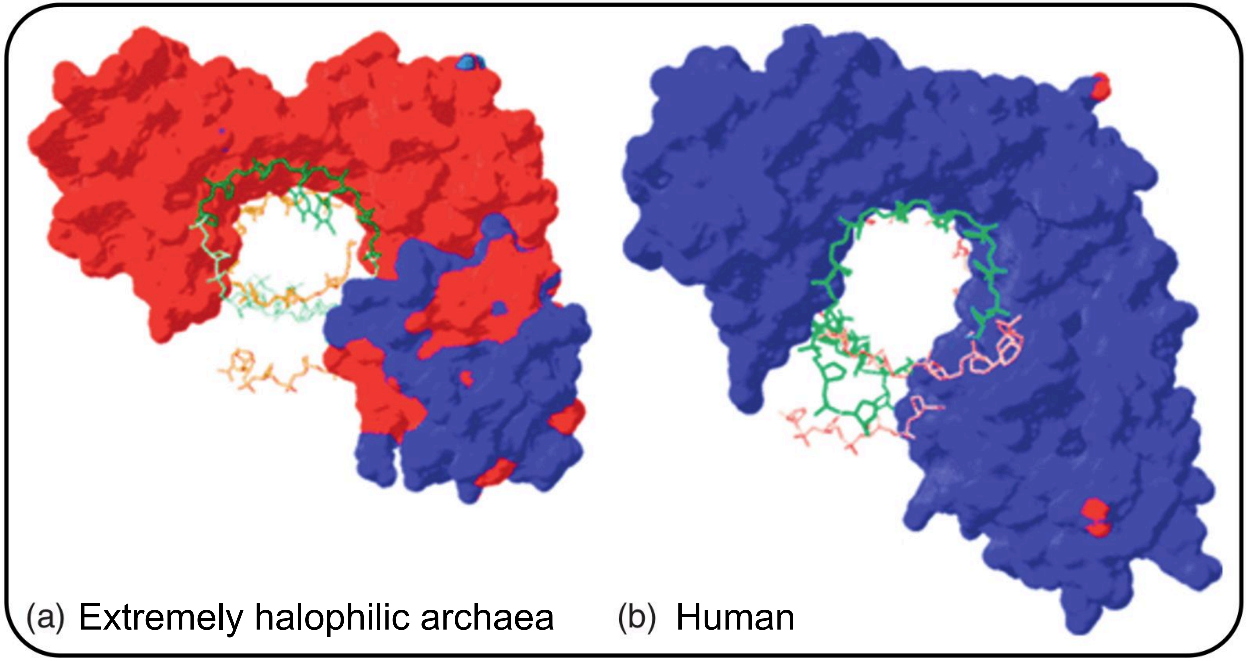
Oren A. (2013)

Physiological adaptation: HIGH SALT-IN STRATEGY

Halobacteriales order

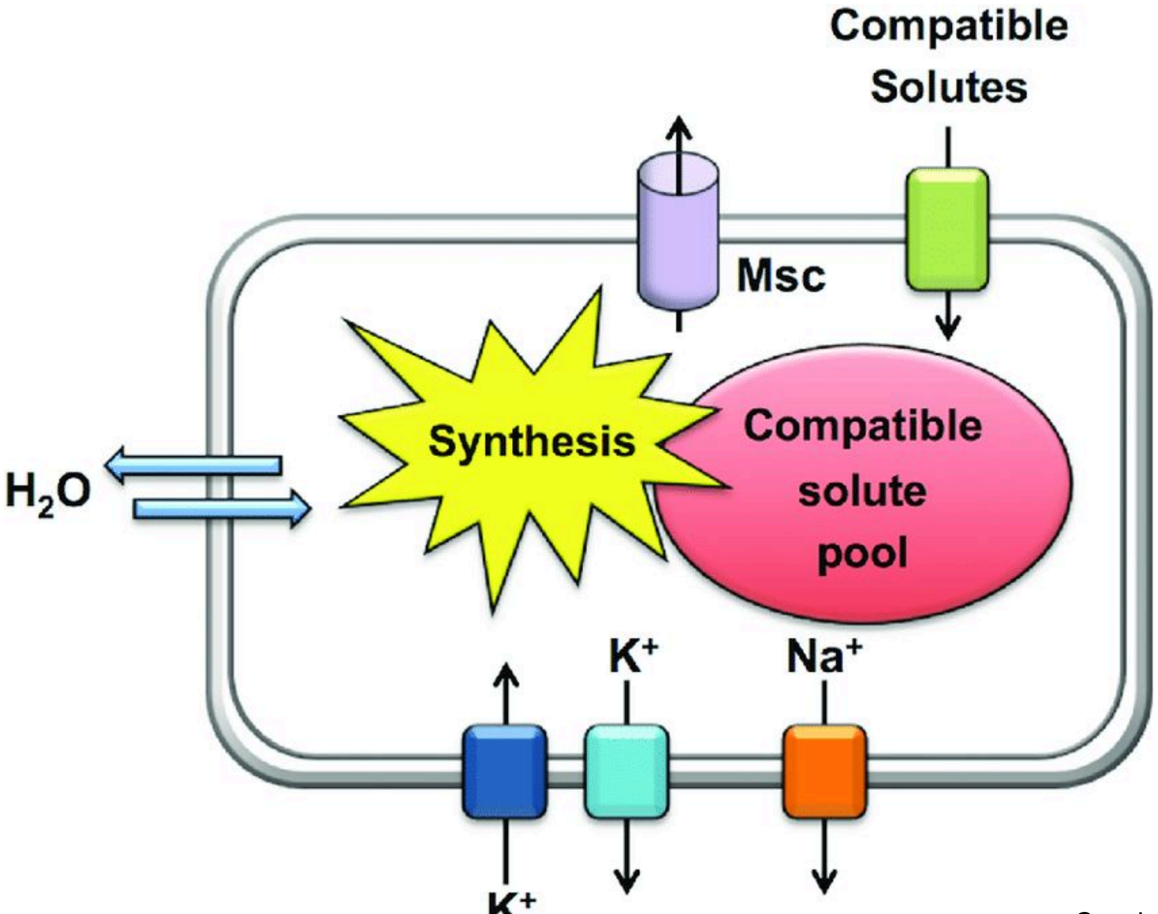
Protein–DNA complexes:
transcription initiation complexes, surrounding the DNA double helix.

Protein surface charges:
Red for **acidic** or negative;
Blue for **basic** or positive.



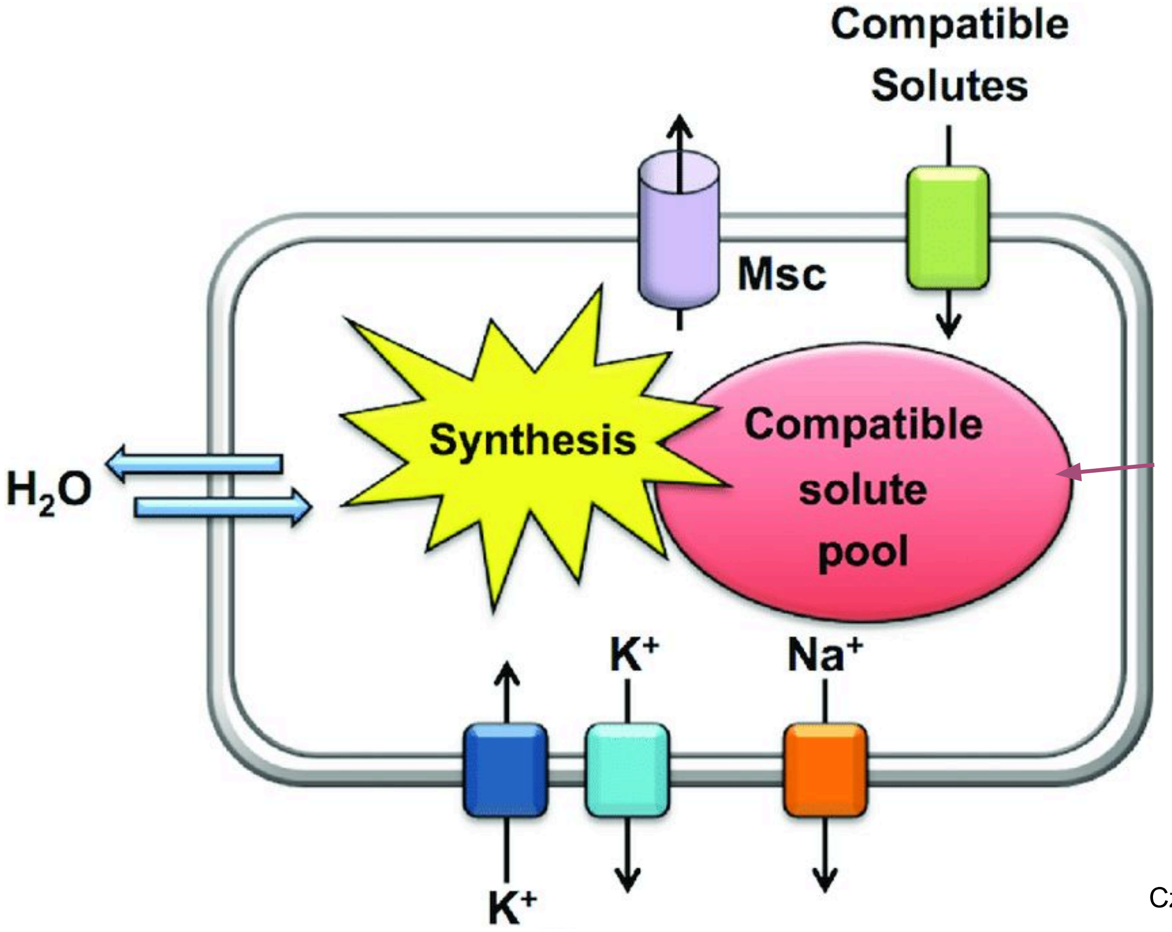
DasSarma and DasSarma (2017)

Physiological adaptation: LOW SALT-IN/SALT-OUT STRATEGY



Czech and Bremer (2018)

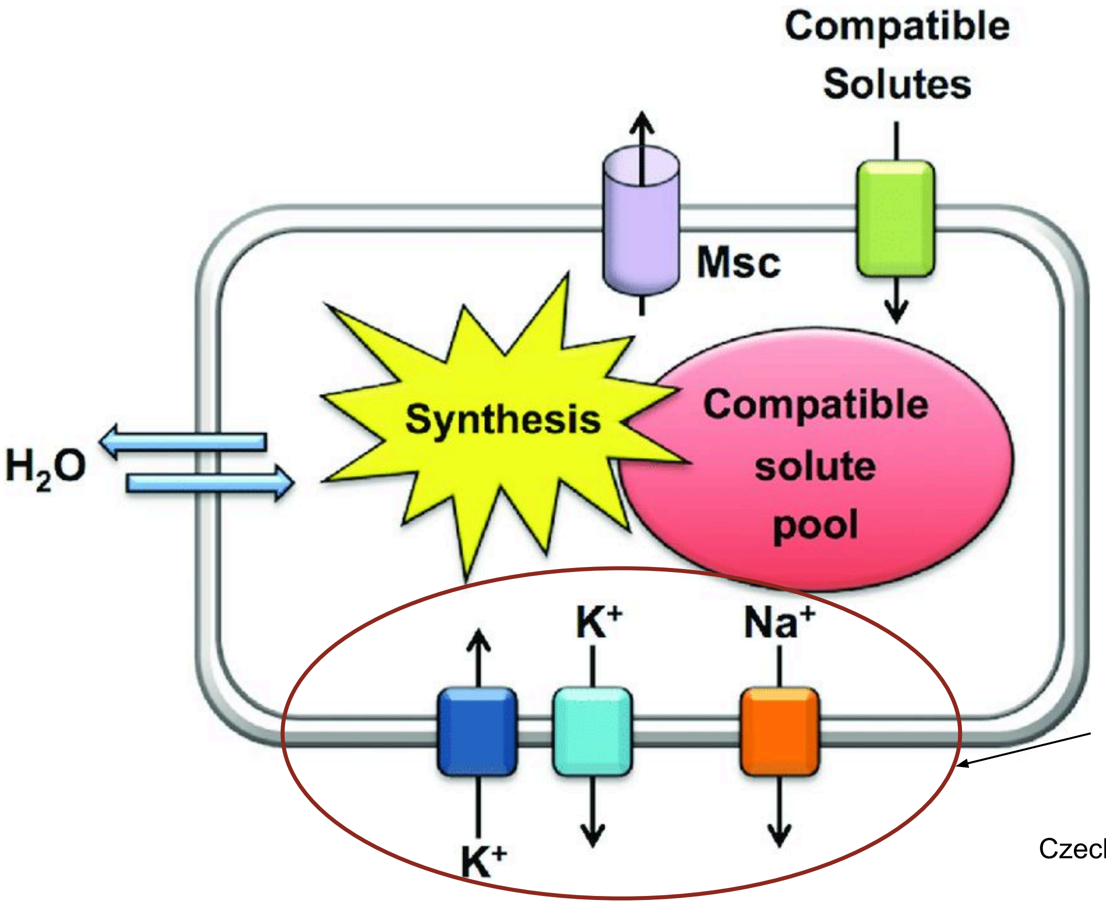
Physiological adaptation: LOW SALT-IN/SALT-OUT STRATEGY



Organic osmolytes that can be amassed to exceedingly high cellular concentrations **without disturbing** vital biochemical and physiological processes.
Many cells **contain cocktails of different compatible solutes** rather than relying on a single compound

Czech and Bremer (2018)

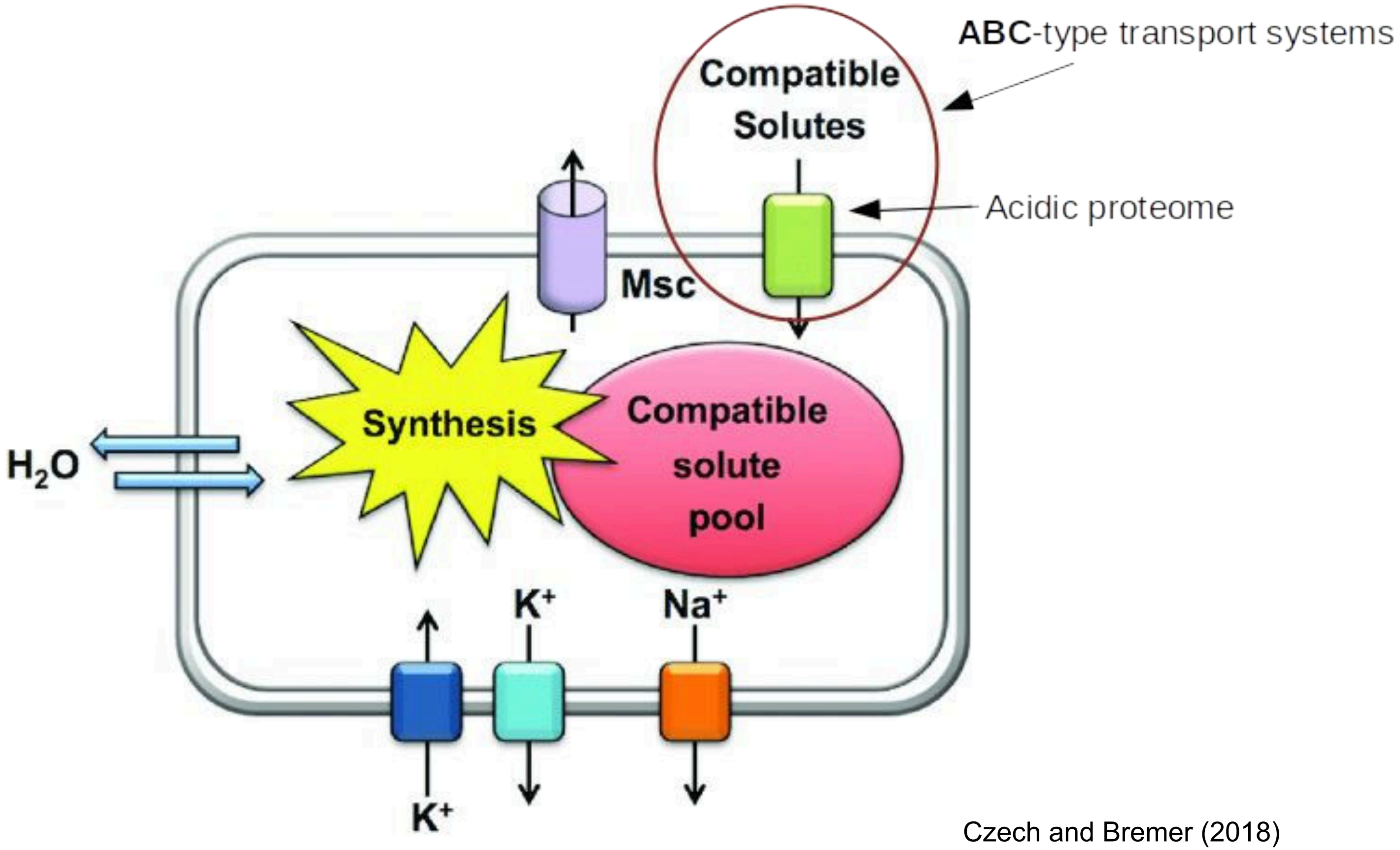
Physiological adaptation: LOW SALT-IN/SALT-OUT STRATEGY



Ionic strength
cytoplasm

Czech and Bremer (2018)

Physiological adaptation: LOW SALT-IN/SALT-OUT STRATEGY



Czech and Bremer (2018)

Physiological adaptation: LOW SALT-IN/SALT-OUT STRATEGY

TABLE 11.2 Structure and distribution of some zwitterionic organic osmolytes within the prokaryotes.

Solute	Distribution
Glycine betaine	Halotolerant and halophilic bacteria, phototrophic *Halorhodosporahalochloris*, aerobic chemoheterotrophic bacteria, methylotrophic bacteria, *Methylarculaterricola*, *Methylophaga* sp., *Sporosarcina pasteurii*, Brevibacterium sp., *Chromohalobacter* sp.
Ectoine	Halotolerant and halophilic bacteria, Heterotrophic Gammaproteobacteria (*Vibrio cholera*, *Halorhodosporahalochloris*, *Halomonas elongate*, *H. variabalis*, *Chromohalobacter salexigens*, *C. israelensis*, *Methylophaga alcalica*, *Halobacillus halophilus*, *Micrococcus* sp., *Bacillus* spp., *Rhodovulum sulfidophilum*, *Brevibacterium* sp.

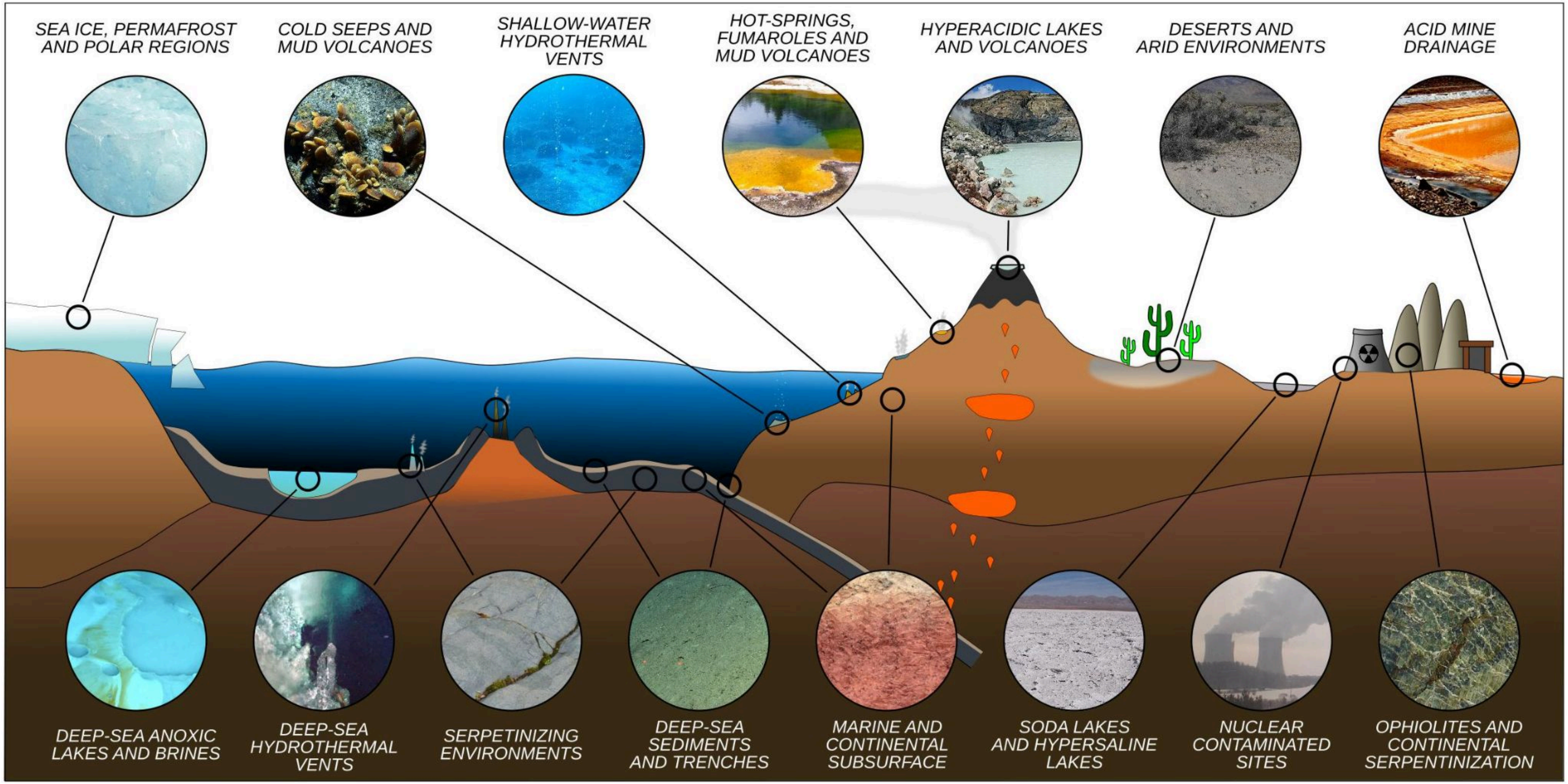
TABLE 11.3 Structure and distribution of selected uncharged organic osmolytes within the prokaryotes.

Solute	Distribution
α-Glucosylglycerol	Marine and fresh water cyanobacteria (*Pseudomonas mendocina*, *P. pseudoalkaligenes*, *Stenotrophomonas*, *Microcyctis firma*)
Trehalose	*Cyanobacteria*, *Halorhodospira* spp., *Sulfolobus solfataricus*, *Thermoproteus tenax*, *Rhodothermusobamensis*, *Desulfovibrio halophilus*, *Thermoplasma acidophilum*
Sucrose	*Cyanobacteria*, *Proteobacteria*

TABLE 11.4 Structure and distribution of selected anionic organic osmolytes (carboxylates, phosphate, sulfate) within the prokaryotes.

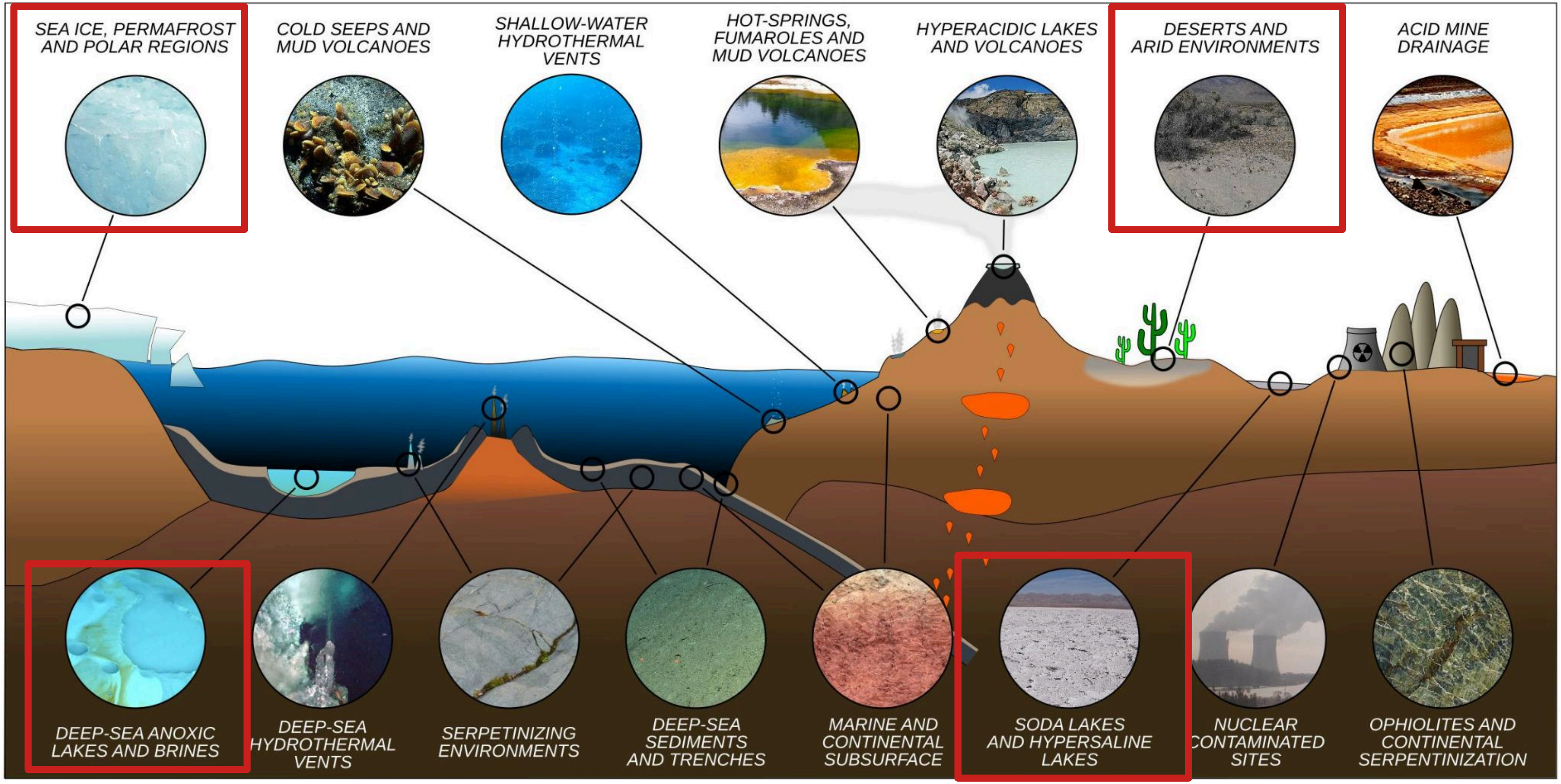
Solute	Distribution	References
α-glutamate	Many halophilic bacteria and methanogens (*Halomonas elongata*, *Halobacterium salinarum*, *Methanophilus portucalensis*	[88]
β-glutamate	Methanogenic Archaea (*Metahnothermococcus thermolithotropicus*)	[88–91]

Salinity: Ecology – Environments



Merino et al., 2019

Salinity: Ecology – Environments



Merino et al., 2019

POLI- EXTREMOPHILES!!!

Salinity: Ecology – Environments

Types of saline environments:

1. **Based on the genesis of the environment:** Artificial or of natural origin.
   a. *Solar salterns* → Artificial
   b. *salt lakes*
   c. *saline soils*
   d. *deep-sea brines, ecc…*

   Natural

2. **Based on the genesis of the salts present:** Thalassic and athalassic:
   a. *Marine salts;*
   b. *Non marine salts.*

Salinity: Ecology – Environments

ECOLOGY - ENVIRONMENTS: artificial solar hypersaline environments

Solar salterns

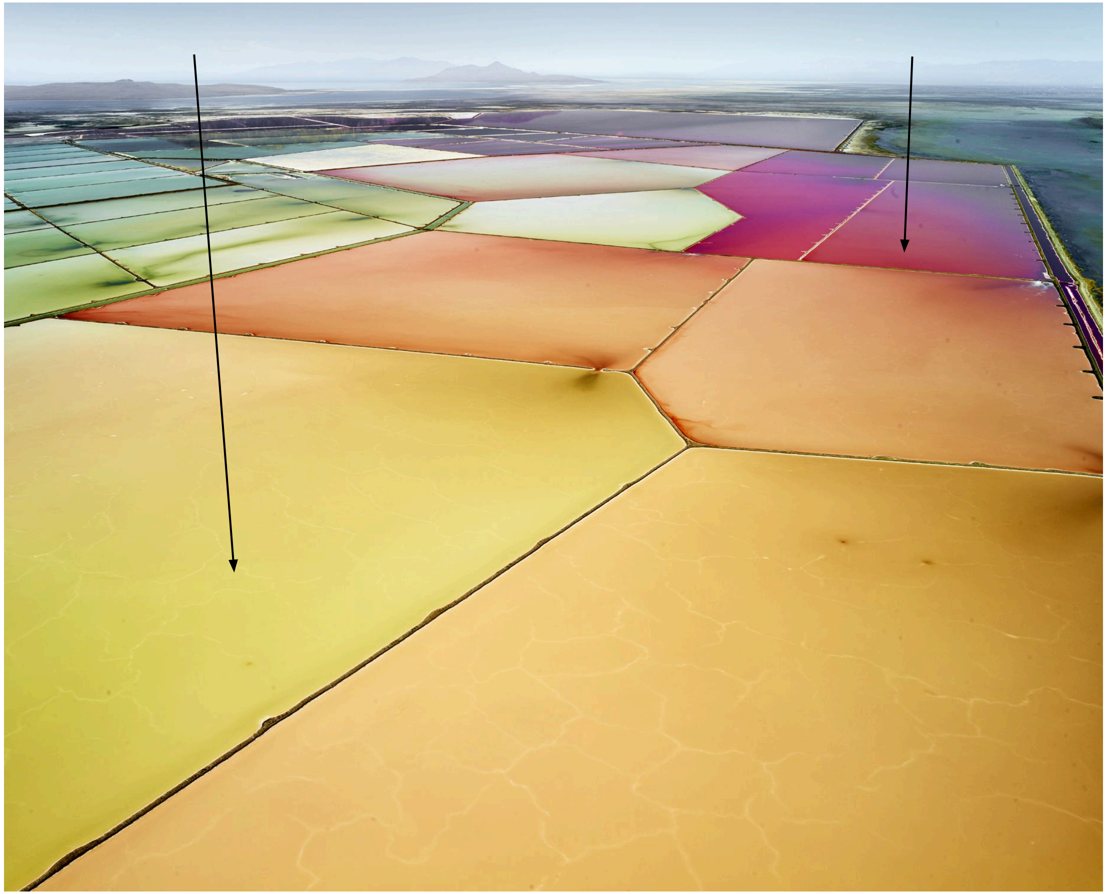
Multi pond solar salterns consist of a series of **interconnected shallow ponds** with increasing salinity, from sea water to NaCl saturation (~26% at 20°C).

Succession of different groups of microorganisms

Fernando Santos and Josefa Antón (2019)

Salinity: Ecology – Environments

ECOLOGY - ENVIRONMENTS: artificial hypersaline environments



Solar salterns

High presence of carotenoids in microbial community

Example:

***Salinibacter ruber* :** photosynthesis antenna pigments

Salinity: Ecology – Environments

ECOLOGY - ENVIRONMENTS

SODA LAKES: most alkaline naturally occurring environments on Earth

Alkaliphilic halophile

Dominant microbial community composed of:

Aerobic, organotrophic, halophilic and alkaliphilic bacterial and archaeal phyla

Anaerobic, alkaliphilic microbial community

Lake Natron, Tanzania.

Yakimov et al., 2001

Salinity: Ecology – Environments

ECOLOGY - ENVIRONMENTS

DRY DESERT: fluctuations in temperature, desiccation and radiation levels

<u>Xerotolerant</u> halophile

Dominant microbial community:

Bacteria:
Cyanobacteria phylum
Bacteroidetes phylum

Archaea:
Halobacteria class

Primary production represents the main source of carbon

Atacama Desert

Uritskiy et al., 2019

Salinity: Ecology – Environments

ECOLOGY - ENVIRONMENTS

DRY DESERT: fluctuations in temperature, desiccation and radiation levels

Halophilic microbial community compositional shift after a rare rainfall in the Atacama Desert

Gherman Uritskiy, Samantha Getsin, Adam Munn, Benito Gomez-Silva, Alfonso Davila, Brian Glass, James Taylor & Jocelyne DiRuggiero

The ISME Journal **13**, 2737–2749 (2019) | Cite this article

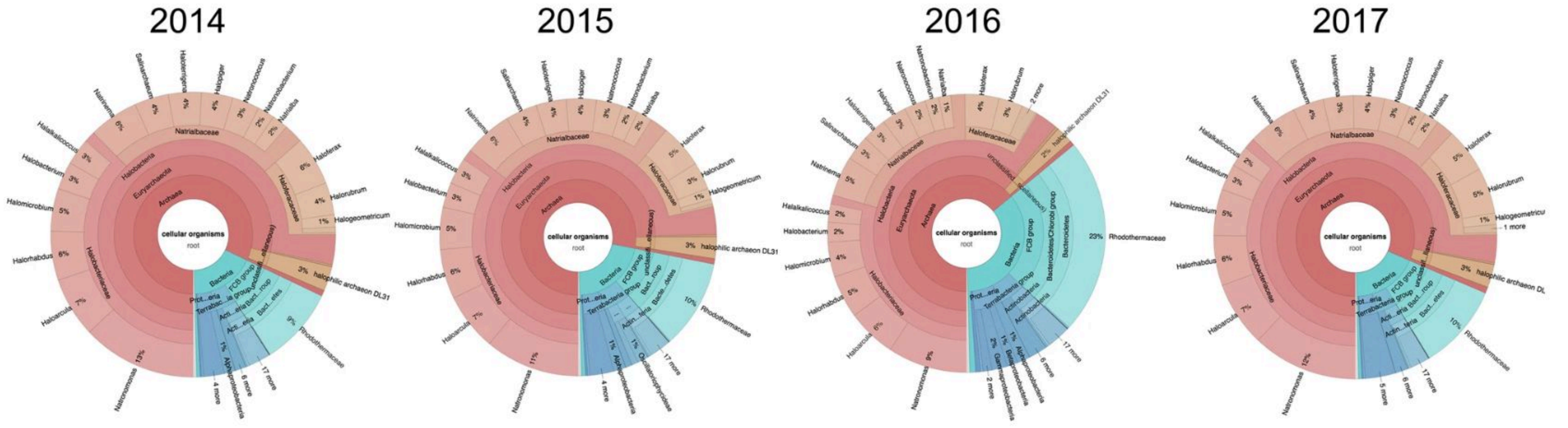
Abstract

Understanding the mechanisms underlying microbial resistance and resilience to perturbations is essential to predict the impact of climate change on Earth's ecosystems. However, the resilience and adaptation mechanisms of microbial communities to natural perturbations remain relatively unexplored, particularly in extreme environments. The response of an extremophile community inhabiting halite (salt rocks) in the Atacama Desert to a catastrophic rainfall provided the opportunity to characterize and de-convolute the

Salinity: Ecology – Environments

ECOLOGY - ENVIRONMENTS

DRY DESERT: fluctuations in temperature, desiccation and radiation levels



Average taxonomic composition of **halite** microbial communities from the same site, before (2014, 2015) and after (2016, 2017) the rain event.

Example of Ecosystem **resilience**!!!

Uritskiy et al., 2019

Salinity: Ecology – Environments

ECOLOGY - ENVIRONMENTS

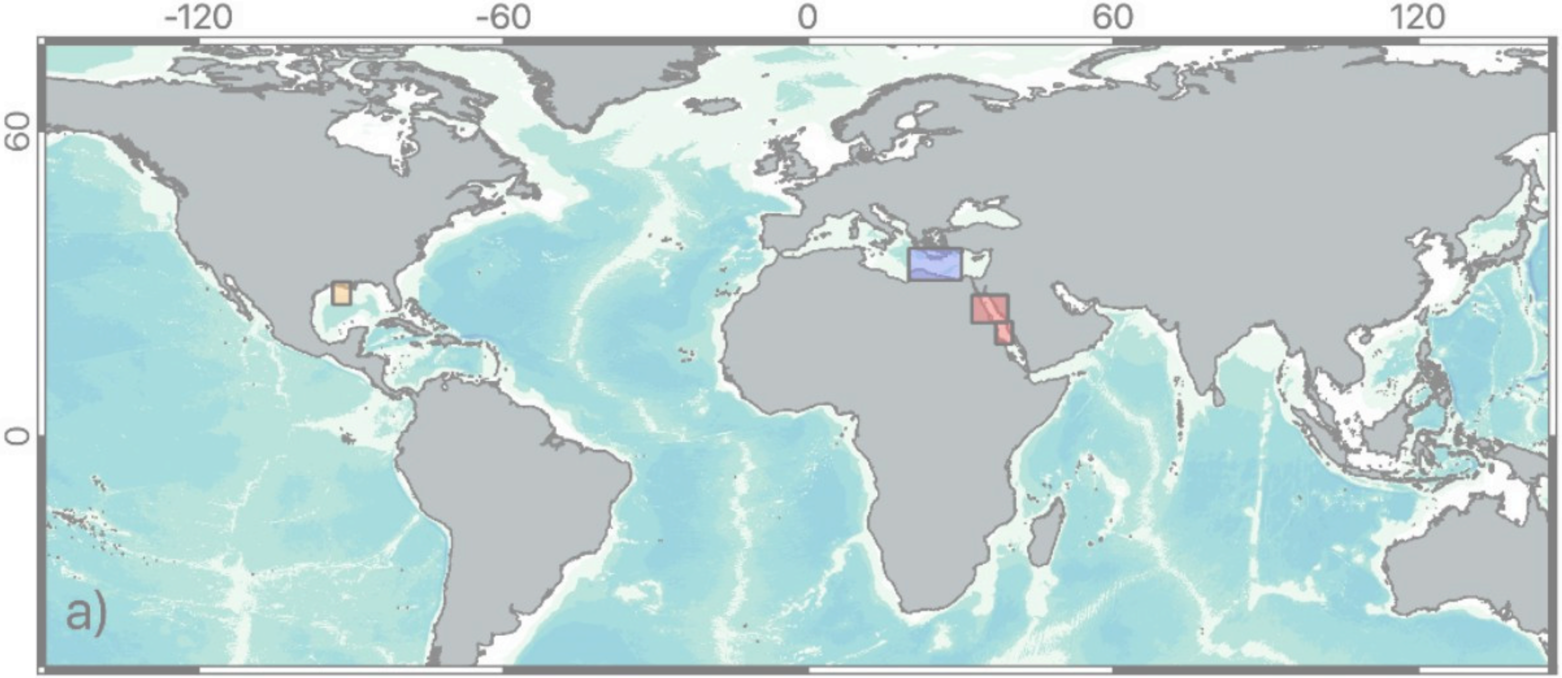
DEEP-HYPERSALINE ANOXIC BASINS: dense bodies of water that have a **salinity** that is **three to eight times** greater than the surrounding **ocean.**

Salinity: Ecology – Environments

ECOLOGY - ENVIRONMENTS

DEEP-HYPERSALINE ANOXIC BASINS:

Gulf of Mexico – Mediterranean Sea – Red Sea



Varrella et al., 2020

Salinity: Ecology – Environments

ECOLOGY - ENVIRONMENTS

DEEP-HYPERSALINE ANOXIC BASINS:

Origin: Salt tectonics

Shallow salty basin

Tectonic shifts

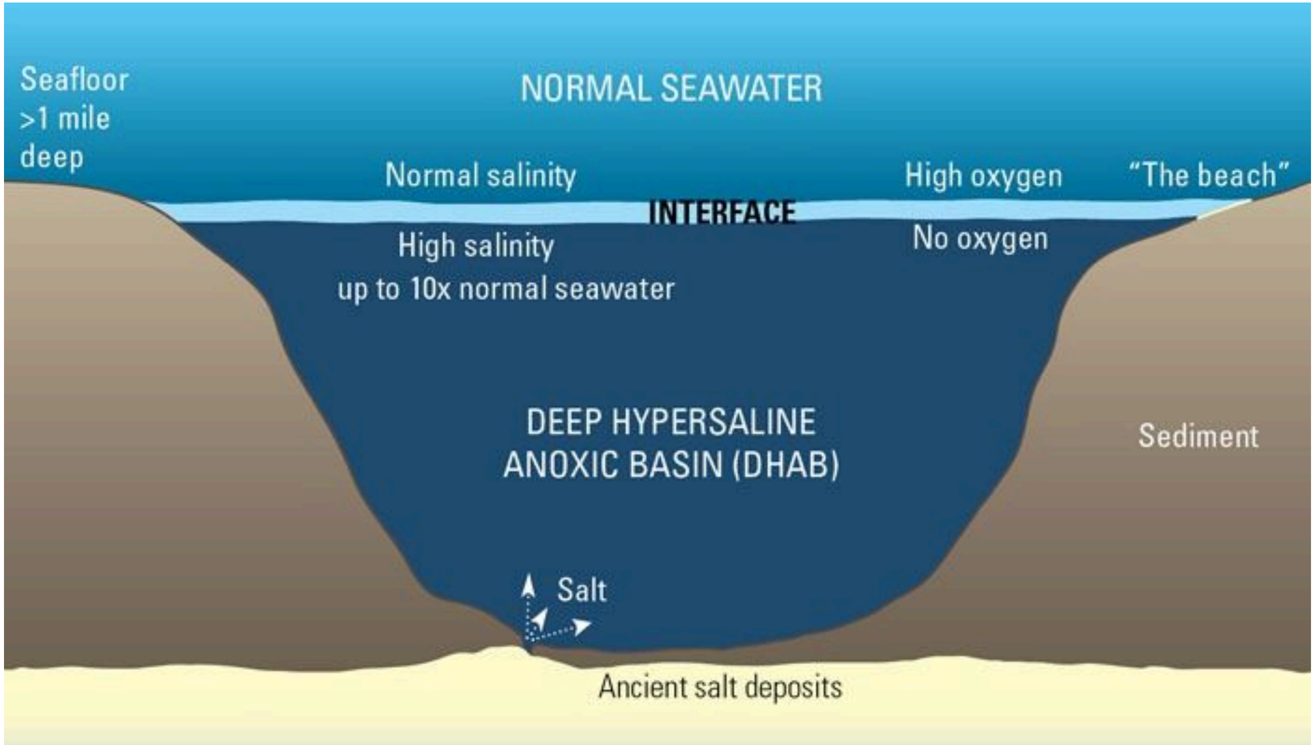
Lowering of the basin

Sediment buring

Crack of the salt dome

Salt rises and dissolves

Brine pool



Salinity: Ecology – Environments

ECOLOGY - ENVIRONMENTS

DEEP-HYPERSALINE ANOXIC BASINS (DHABs):

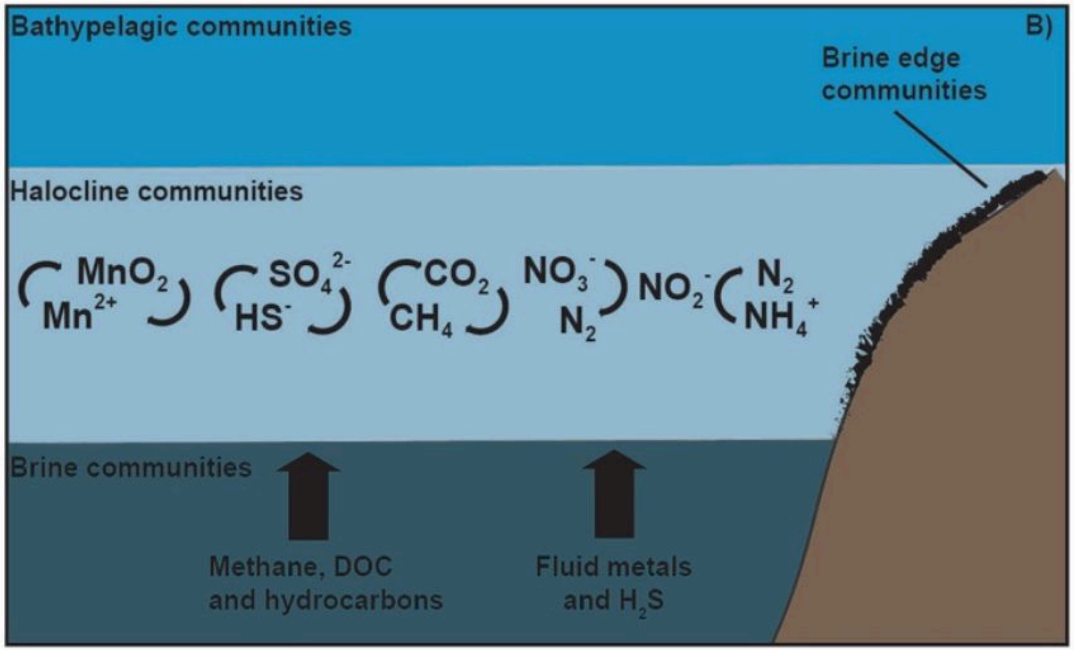
DHAB halophiles

Dominant microbial community:

Highly stratified community between brines and the seawater–brine interfaces;

→*Deltaproteobacteria* sulfate-reducers (anaerobic oxidation of methane);
→*Gamma*- and *Epsilonproteobacteria* sulfide-oxidizer (sulfur-cycling);
→Top-down control made by viruses;

→**Symbiosis** between microbes and mussels allows mussels to grow biomass thanks to the chemosynthetic, C fixing microbes located in their gill tissue

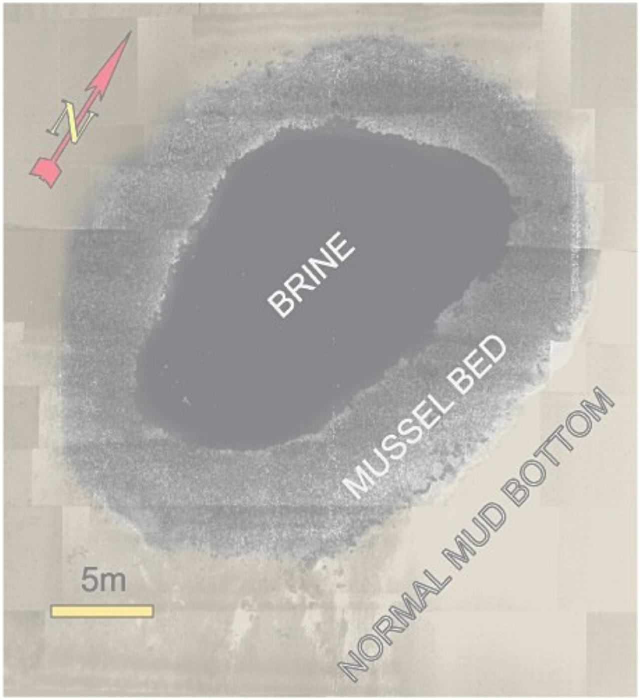


Varrella et al., 2020

Salinity: Ecology – Environments

ECOLOGY - ENVIRONMENTS

DEEP-HYPERSALINE ANOXIC BASINS:



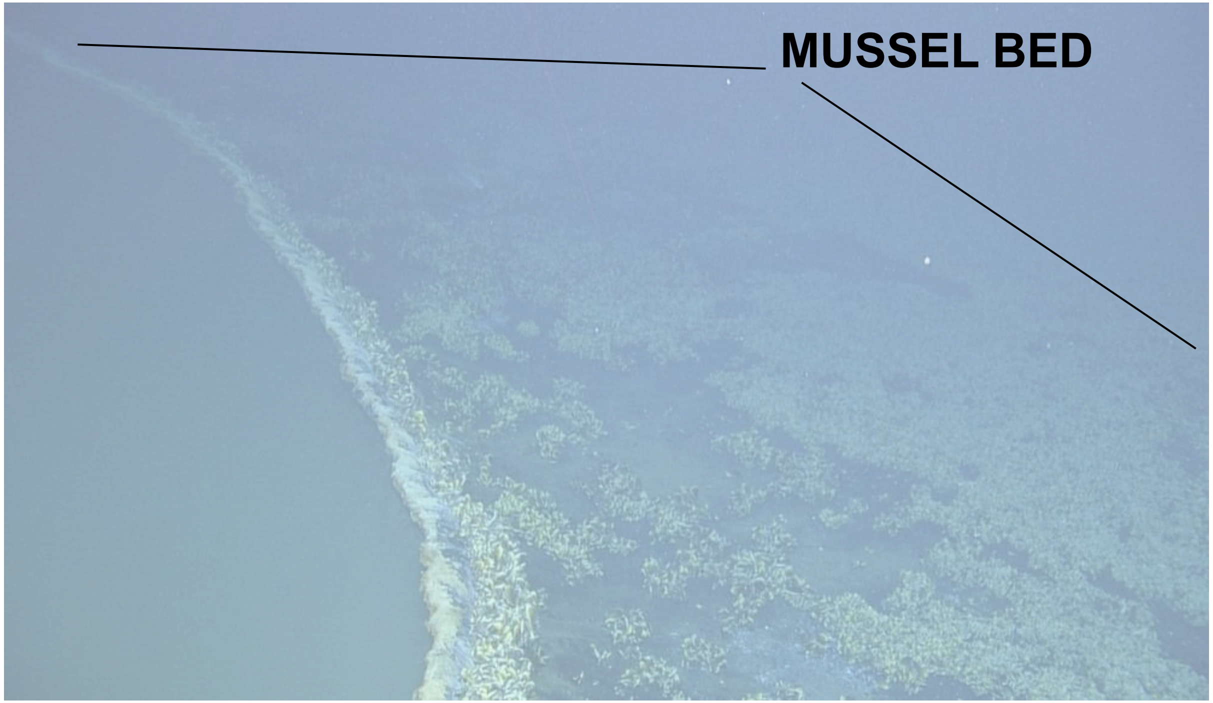


Photo credit: NautilusLive

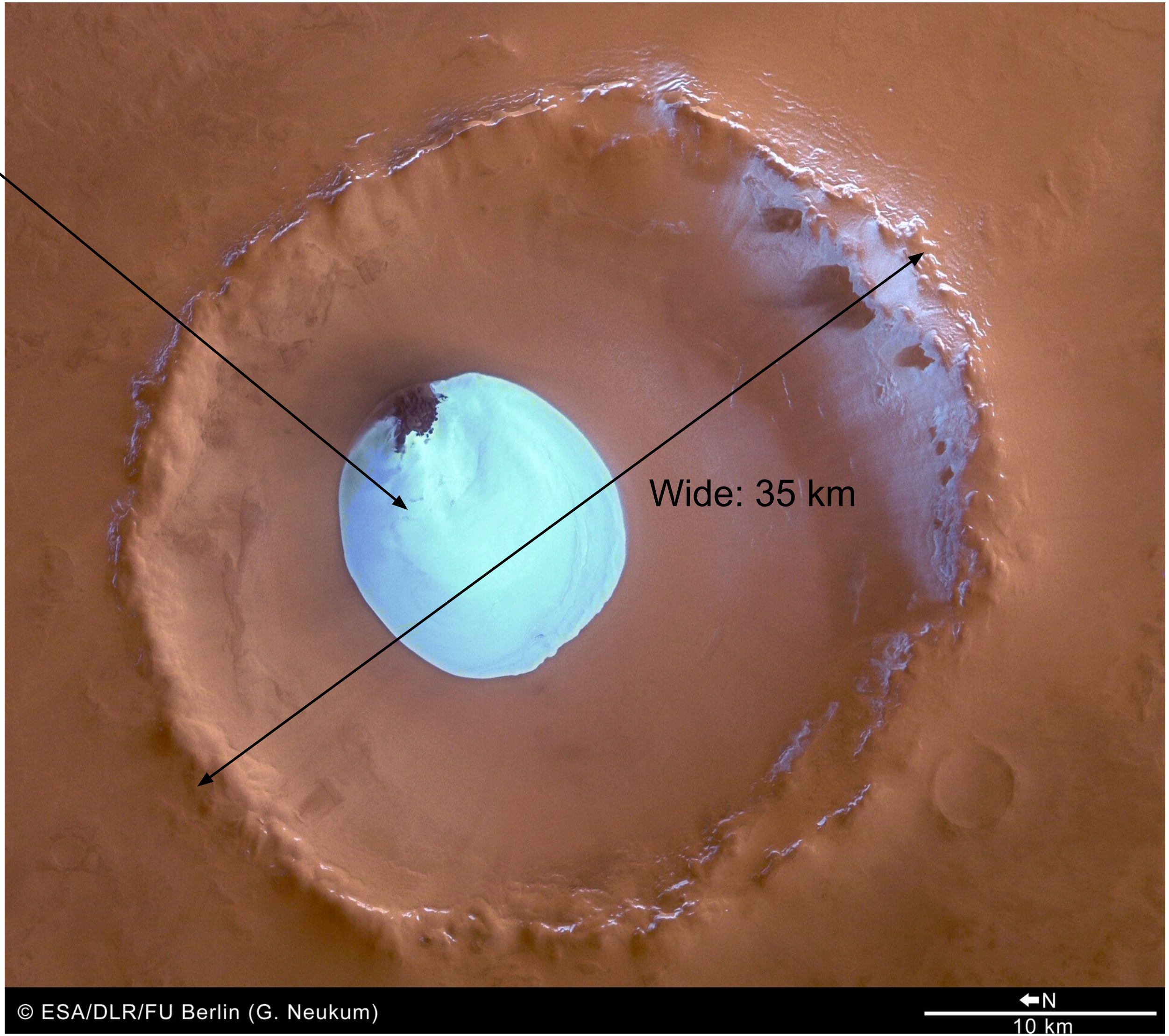
Water ice in crater at Martian north pole

Approximately:
70.5° North and 103° East

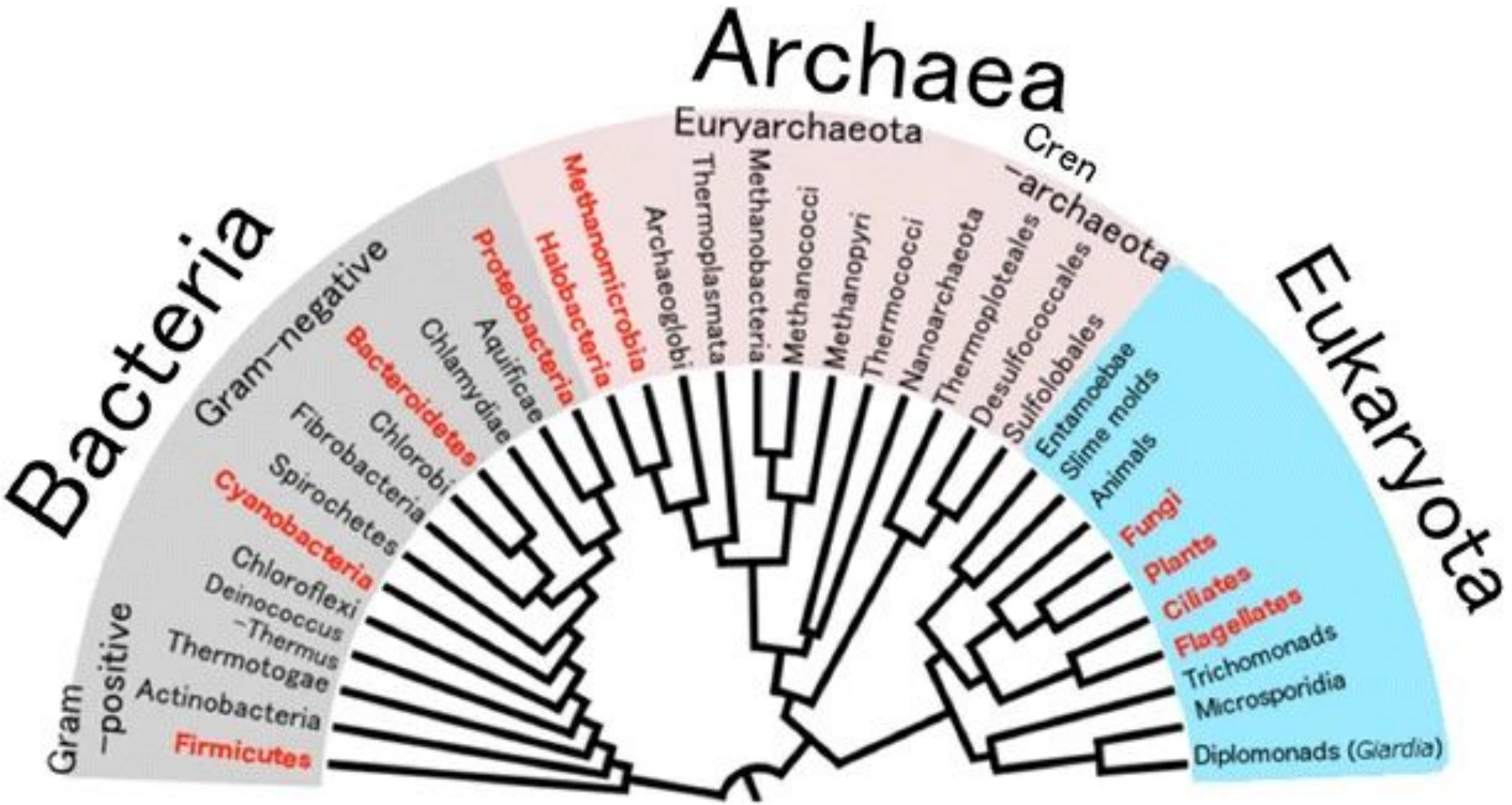
The circular patch of bright material located at the center of the crater is **residual water ice.**

Main hypothesis:

Halophiles are a leading group of microorganisms in the newly developing field of astrobiology and may be key to the search for life elsewhere in the universe. Discovery of recurring slope lineae has suggested the presence of freezing and thawing brine on Mars. **Halophiles may expand the potential habitable zone** in our solar system and on extrasolar planets because of their ability to thrive under challenging conditions



TAXONOMY

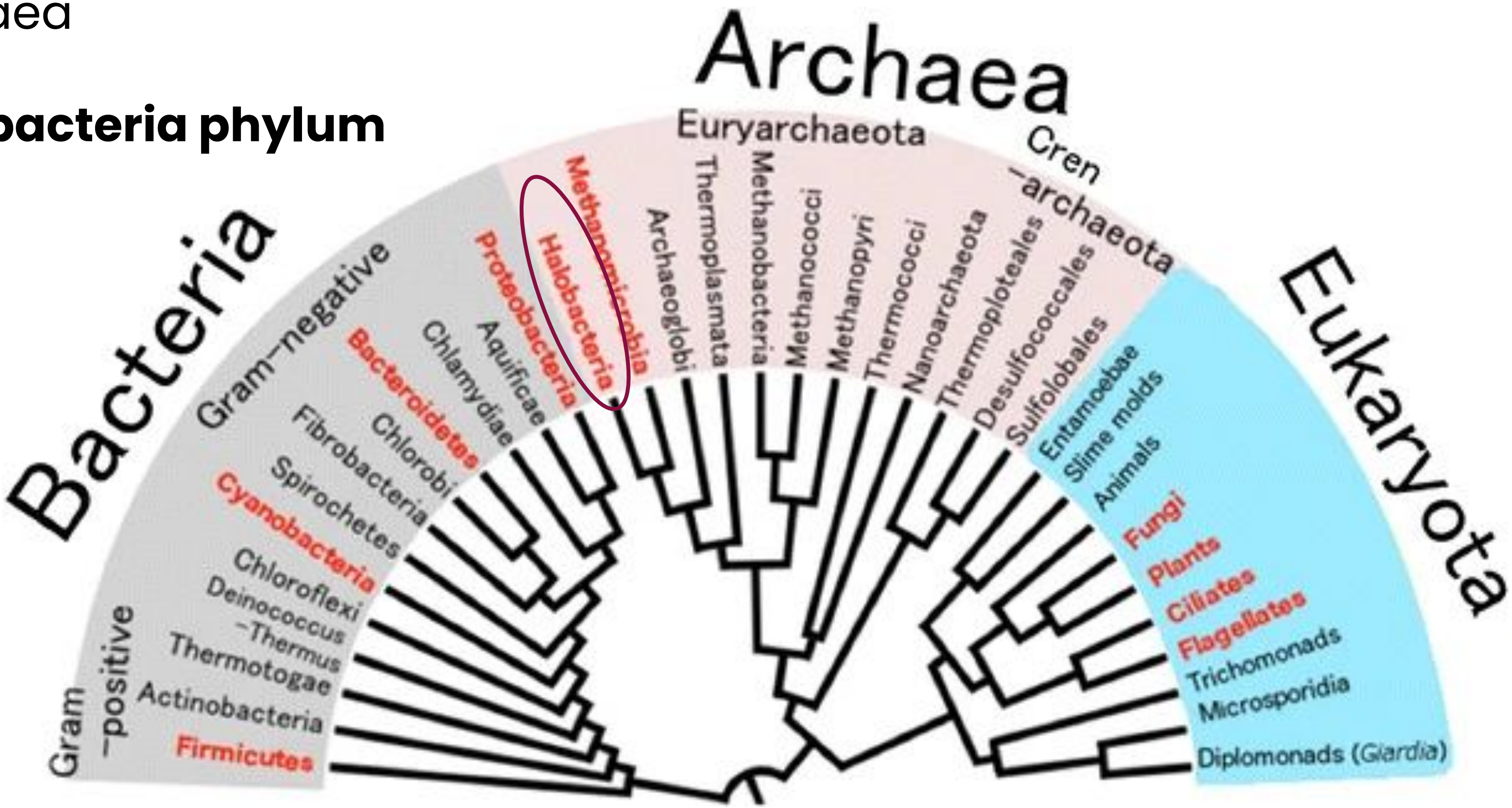


Mohamed Faraj Edbeib et al., 2016

TAXONOMY

Archaea

Halobacteria phylum



Mohamed Faraj Edbeib et al., 2016

Salinity: Taxonomy of halophiles

Archaea

Halobacteria phylum

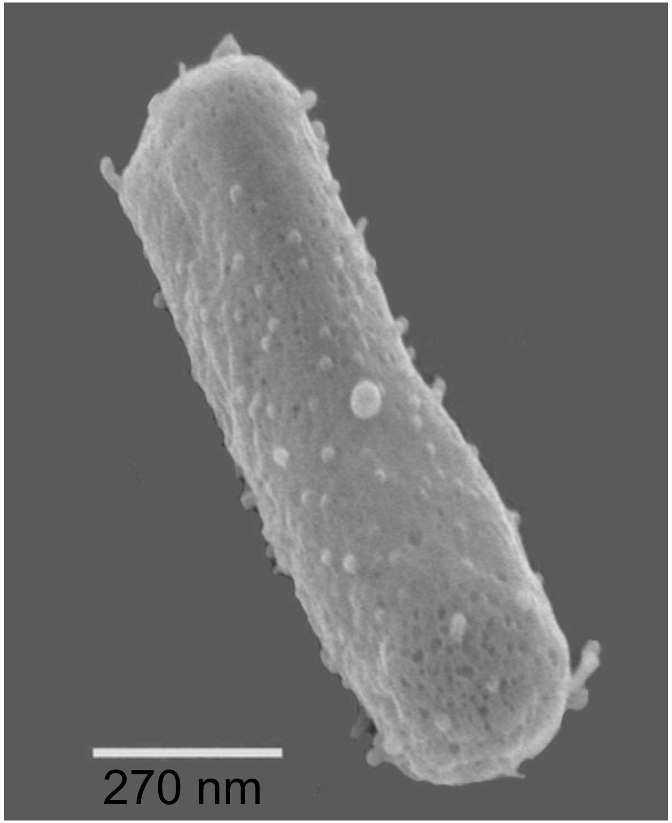
Halobacterium salinarum NRC-1

Energy is obtained by **aerobic**, **anaerobic**, or phototrophic use of the energy of light;

Multiple pathways using organic molecules:
dissimilatory nitrate reduction and **denitrification**, **fermentation** of different sugars, **breakdown** of **arginine** and the use of **light energy** mediated by **retinal pigments**.

Bacteriorhodopsin make purple membranes.
The **membrane potential** generated by bacteriorhodopsin can be used to drive **ATP synthesis** and maintain phototrophic growth. **Halorhodopsin also contributes to phototrophic growth** because of its inwardly-directed light-driven chloride pump.

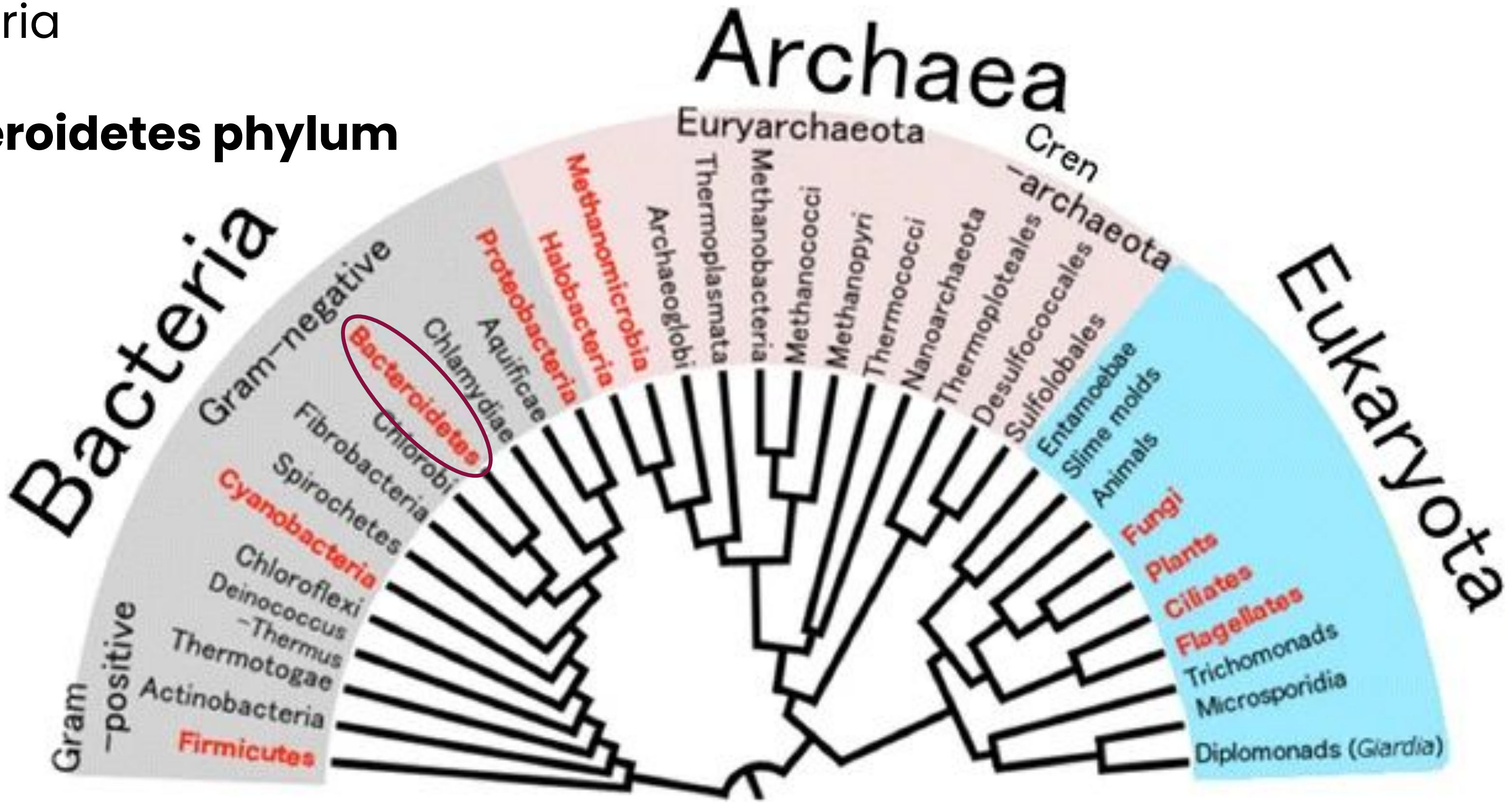
H. NRC-1 is found to grow on either dimethyl sulfoxide (DMSO) or trimethylamine N-oxide (TMAO)



TAXONOMY

Bacteria

Bacteroidetes phylum



Mohamed Faraj Edbeib et al., 2016

Salinity: Taxonomy of halophiles

Bacteroidetes phylum

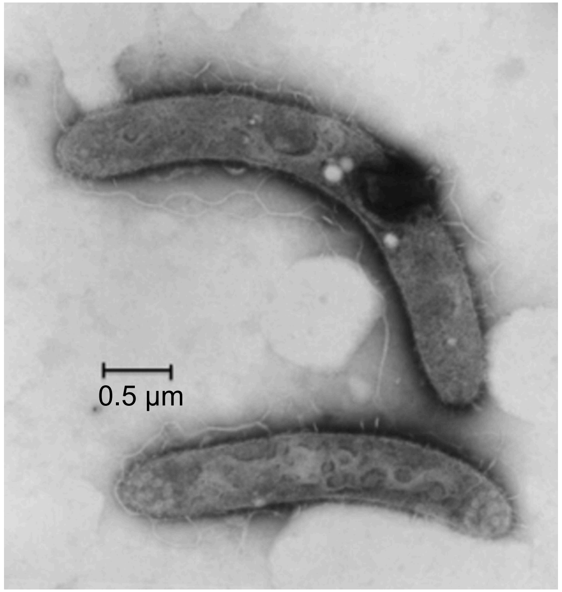
***Salinibacter ruber*:** gram-negative aerobic heterotroph

S. ruber itself **cannot grow below 15% salt concentration**, with an **ideal concentration between 20-30%.**

Within the genome of S. ruber, there is a hypersalinity island, which is extremely crucial for survival in a halophilic environment. This cluster of 19 genes includes a K+ uptake/efflux systems and cationic amino acid transporters.

Salinibacter produces an **unusual carotenoid**, salinixanthin that forms a light antenna and transfers energy to the retinal group of xanthorhodopsin, a light-driven proton pump.

S. ruber uses a modified **Entner–Doudoroff pathway** (phosphorylation step is delayed). **Glycerol** is abundantly used for growth, as it is one of the most common substrates in saltern lakes. **Glycerol metabolism** starts with the phosphorylation of glycerol by glycerol kinase, followed by dehydrogenation of glycerol 3-phosphate.



Electron micrograph of Salinibacter ruber strain Pola-18

Mongodin EF et al., 2005 ; Oren et al., 2003,2013

BIOTECHNOLOGICAL APPLICATIONS

They are notably able to produce **bacteriorhodopsin** used, for example, in **optical data processing**, as **light sensors** or in **holography**.

They also generate **exopolysaccharides** and **polyhydroxyalkanoates** that could advantageously **replace conventional petrol-derived plastics** in the future due to their **easy biodegradability**.

In addition, to compensate for the high osmotic pressure of their environments, a large diversity of **moderate halophiles and halotolerant** microorganisms **produce** high concentrations of **compatible solutes** such as **amino acids** (glycine and proline), glycine- and glutamate-betaines, choline, glycerol, trehalose, and **ectoines**, the latter being already commercially produced.

Halophiles: Biotech Applications


Plant-Microbe Interaction: An Approach to Sustainable Agriculture pp 297-325 | Cite as

Halophilic Bacteria: Potential Bioinoculants for Sustainable Agriculture and Environment Management Under Salt Stress

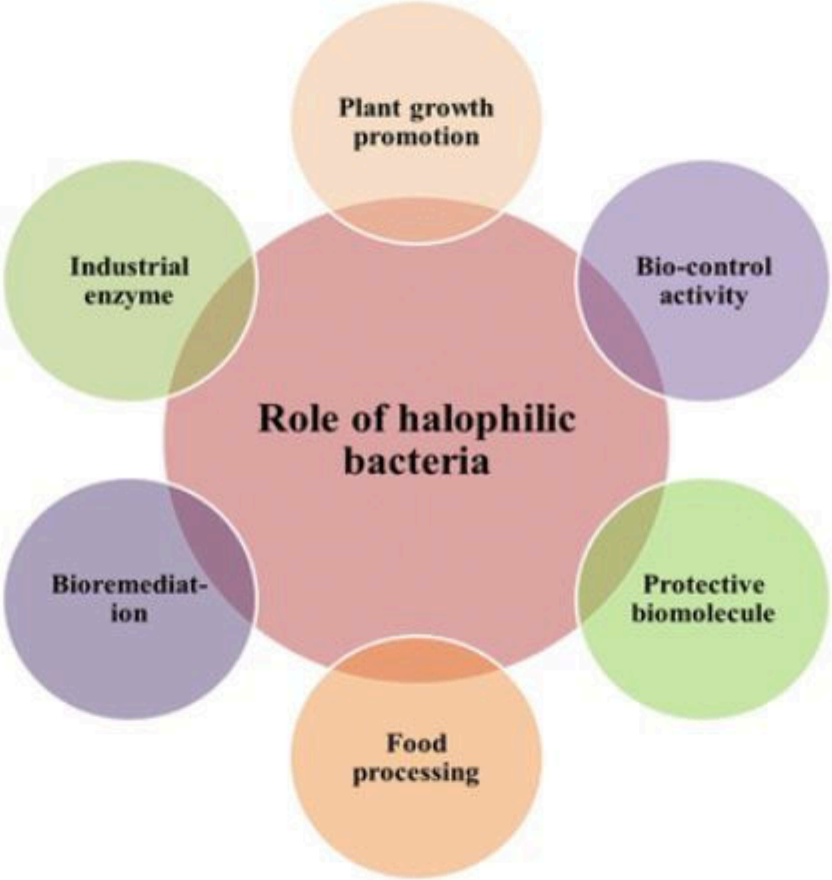
Authors   Authors and affiliations

Anjney Sharma, Anukool Vaishnav, Hena Jamali, Anchal Kumar Srivastava, Anil Kumar Saxena, Alok Kumar Srivastava

Chapter
First Online: 10 February 2017

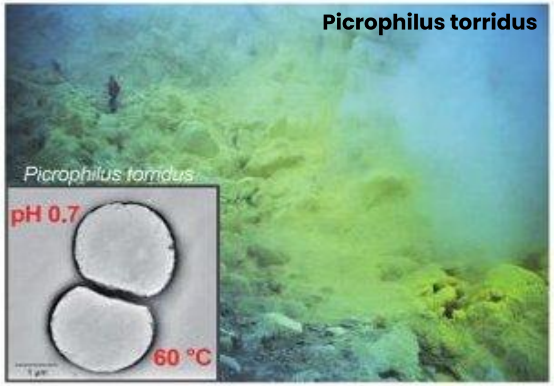
Abstract

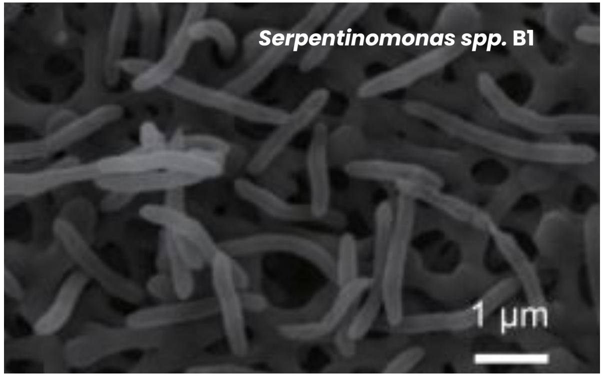
Salinity is one of the most critical environmental constraints which cause soil degradation and hampering agricultural production throughout the world. In the present time, a total 831 million hectares of land is affected by salinity. The salinity affects the processes in plant life from its germination to maturation stage. Regulation of phytohormones, root/shoot development, nutrient uptake, and photosynthesis are severely affected by salt stress and ultimately reduce agricultural productions. The loss of agriculture production due to salinization is one of the major constraints to feed to the growing population. High salt levels in the soil limit its agroecological potential and represent a considerable ecological and socioeconomic threat to sustainable development. In this context, the use of halophilic bacteria

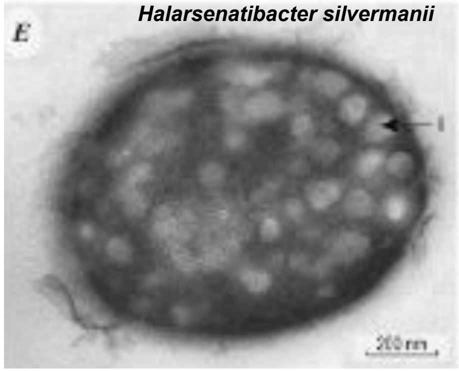


SUMMARY

Strain	Domain	Type of extremophile	Isolated from	Temp. (°C)	pH	Salinity (%)	References
Picrophilus oshimae KAW 2/2	Archaea	Hyper-acidophile	Hot springs, Solfataras	47-65	**-0.06**-1.8	0-20	Schleper et al. 1995, 1996
Serpentinomonas sp. B1	Bacteria	Hyper-alkaliphile	Serpentinizing fluids	18-37	9-**12.5**	0-0.5	Suzuki et al. 2014; Bird et al. 2021
Halarsenatibacter silvermanii SLAS-1	Bacteria	Halo-alkaliphile	Soda lake	28-55	8.7-9.8	20-**35**	Oremland et al. 2005







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