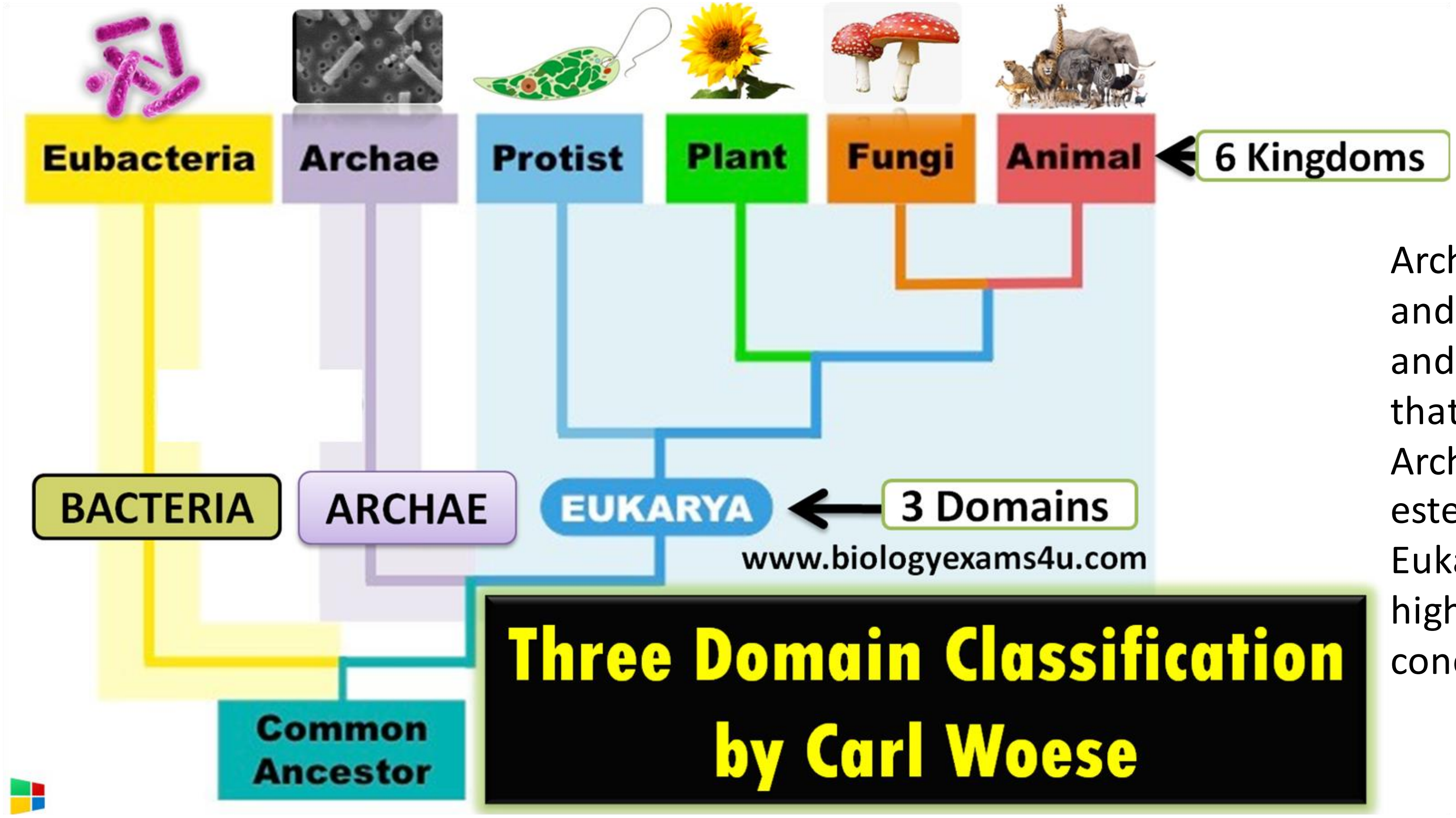
ADAPTATION TO EXTREME ENVIRONMENTAL CONDITIONS

EXTREMOPHILES



Archaea often live in extreme environments and include methanogens, extreme halophiles, and hyperthermophiles. One reason for this is that the **ether-containing linkages** in the Archaea membranes is more stabile than the ester-containing linkages in the Bacteria and Eukarya and are better able to withstand higher temperatures and stronger acid concentrations.

There are various hypotheses as to the origin of prokaryotic and eukaryotic cells.
Because all cells are similar in nature, it is generally thought that all cells came from a common ancestor cell termed the last universal common ancestor (LUCA).
These LUCAs eventually evolved into three different cell types, each representing a domain.
The three domains are the Archaea, the Bacteria, and the Eukarya.

What are Extremophiles?

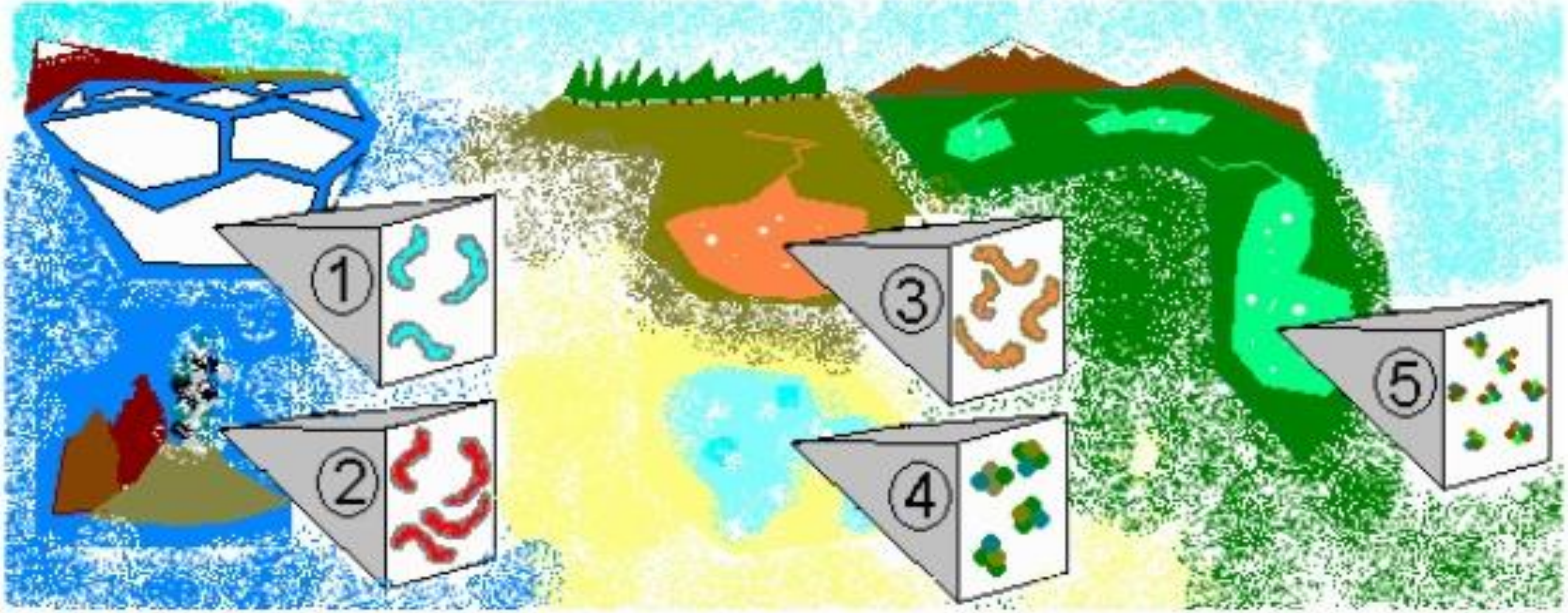
Extremophiles are microorganisms— whether viruses, prokaryotes, or eukaryotes— that survive under harsh environmental conditions that can include atypical temperature, pH, salinity, pressure, nutrient, oxic, water, and radiation levels

Microbiology of extreme environments

- temperature
- pH
- humidity/water
- salinity
- sugar
- pressure
- rocks
- heavy metals
- radiations

Types of Extremophiles



1) Psychrophiles
Microbes that live in cold environments like sea ice and the arctic and antarctic ice packs.

2) Thermophiles
Microbes that live in very hot environments like deep sea vents and volcanic lakes.

3) Alkaliphiles
Microbes that live in basic environments like soda lakes.

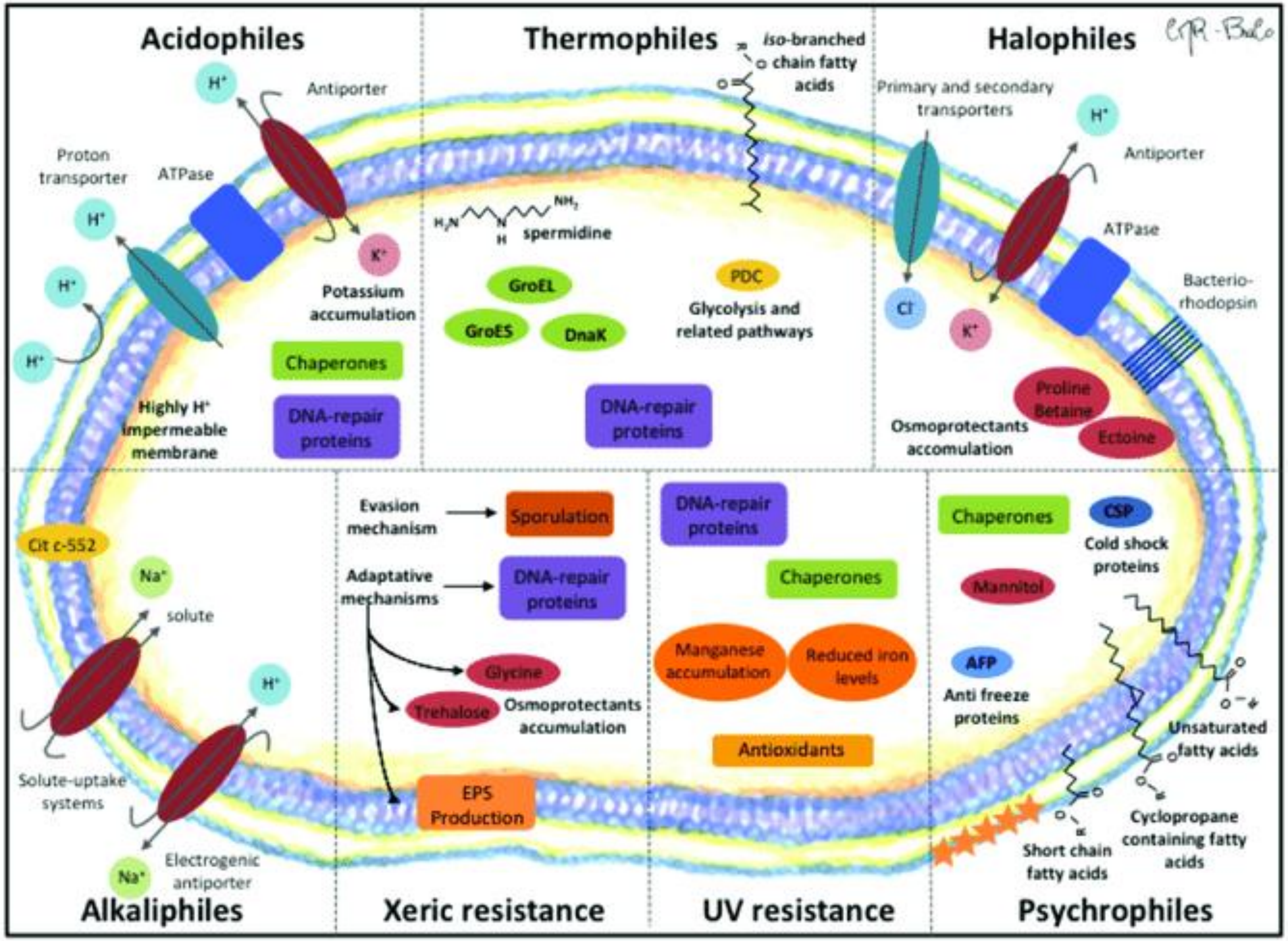
4) Halophiles
Microbes that live in very salty environments like salt lakes and salt mines.

5) Acidophiles
Microbes that live in acidic environments like sulphur springs.

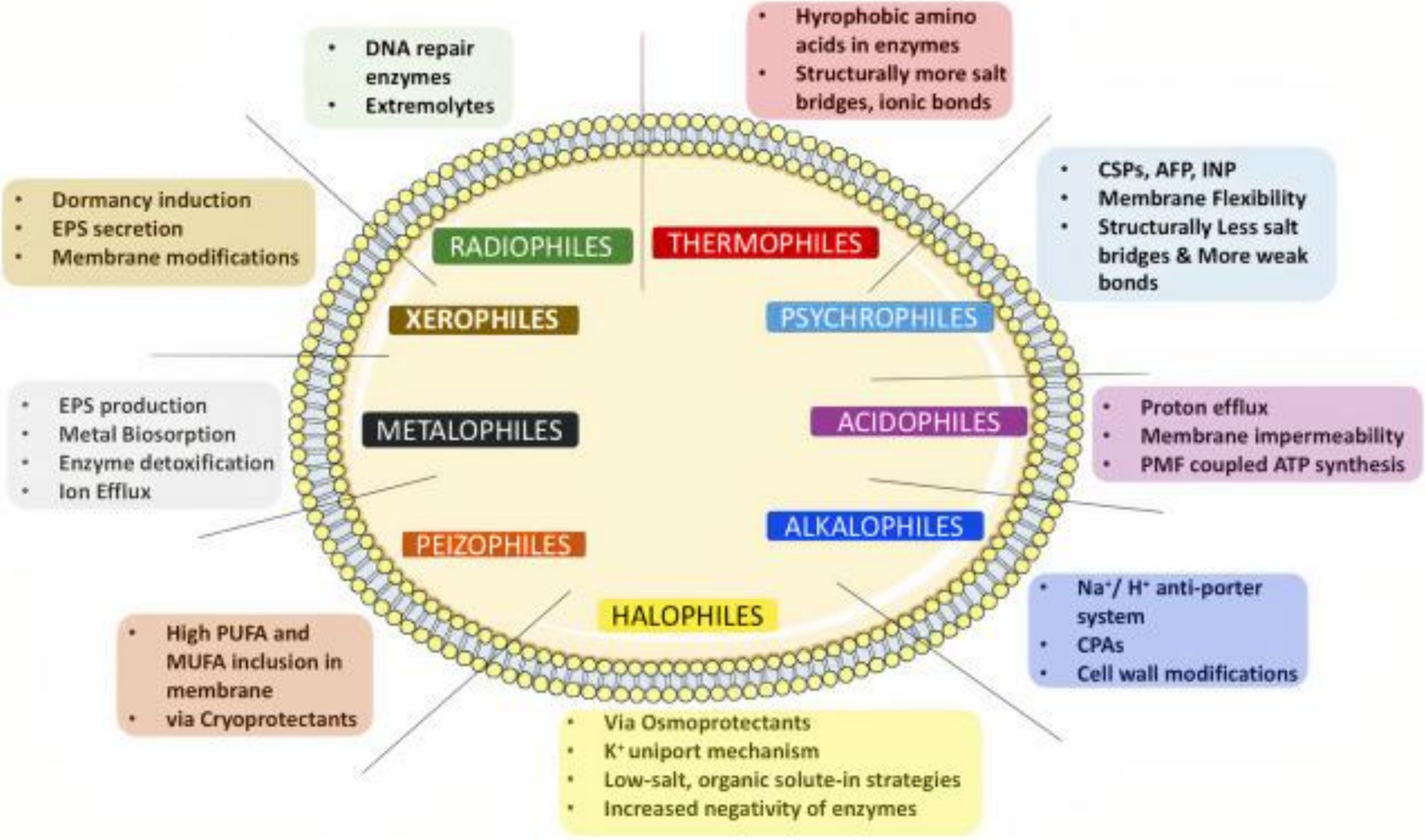
Types of Extremophiles

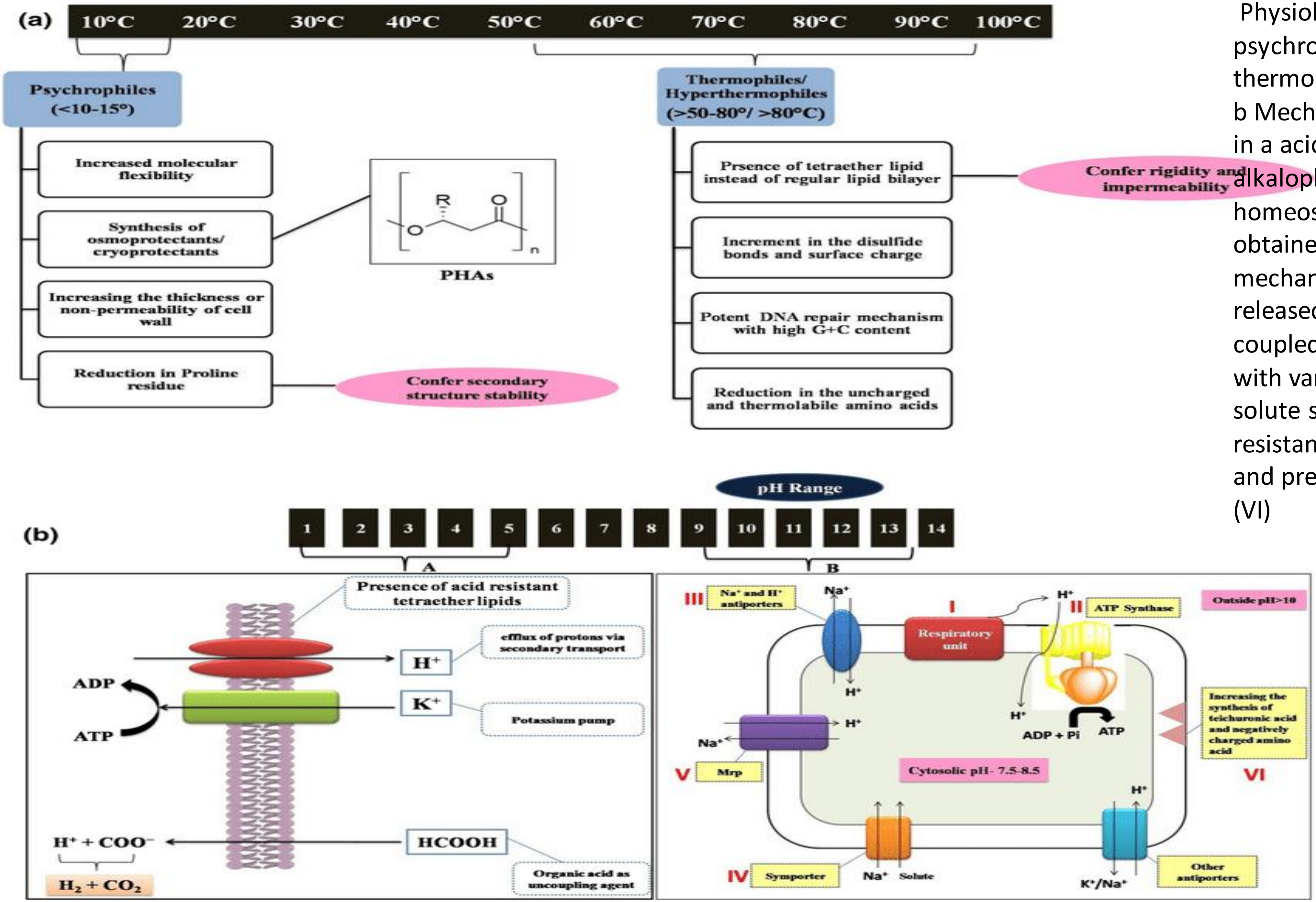
Other types include:

- Barophiles -survive under high pressure levels, especially in deep sea vents
- Osmophiles –survive in high sugar environments
- Xerophiles -survive in hot deserts where water is scarce
- Anaerobes -survive in habitats lacking oxygen
- Microaerophiles -survive under low-oxygen conditions only
- Endoliths –dwell in rocks and caves
- Toxitolerants -organisms able to withstand high levels of damaging agents. For example, living in water saturated with benzene, or in the water-core of a nuclear reactor



Acidophiles
Thermophiles
Halophiles
Antiporter
Proton transporter
ATPase
H⁺
K⁺
Potassium accumulation
Chaperones
DNA-repair proteins
Highly H⁺ impermeable membrane
iso-branched chain fatty acids
spermidine
GroEL
GroES
DnaK
PDC
Glycolysis and related pathways
Primary and secondary transporters
Cl⁻
Bacterio-rhodopsin
Proline
Betaine
Ectoine
Osmoprotectants accomulation
Cit c-552
Na⁺
solute
Solute-uptake systems
Electrogenic antiporter
Evasion mechanism
Sporulation
Adaptative mechanisms
Glycine
Trehalose
Osmoprotectants accumulation
EPS Production
Manganese accumulation
Reduced iron levels
Antioxidants
CSP
Cold shock proteins
Mannitol
AFP
Anti freeze proteins
Unsaturated fatty acids
Cyclopropane containing fatty acids
Short chain fatty acids
Alkaliphiles
Xeric resistance
UV resistance
Psychrophiles


DNA repair enzymes
Extremolytes
Hyrophobic amino acids in enzymes
Structurally more salt bridges, ionic bonds
Dormancy induction
EPS secretion
Membrane modifications
CSPs, AFP, INP
Membrane Flexibility
Structurally Less salt bridges & More weak bonds
RADIOPHILES
THERMOPHILES
XEROPHILES
PSYCHROPHILES
EPS production
Metal Biosorption
Enzyme detoxification
Ion Efflux
METALOPHILES
ACIDOPHILES
Proton efflux
Membrane impermeability
PMF coupled ATP synthesis
ALKALOPHILES
PEIZOPHILES
HALOPHILES
Na^+/ H^+ anti-porter system
CPAs
Cell wall modifications
High PUFA and MUFA inclusion in membrane
via Cryoprotectants
Via Osmoprotectants
K^+ uniport mechanism
Low-salt, organic solute-in strategies
Increased negativity of enzymes



Physiological adaptations in psychrophiles and thermophiles/hyperthermophile b Mechanismof pH homeostasis in a acidophiles and b alkalophiles. The pH homeostasis in alkaliphiles is obtained via different mechanism i.e., (I) the H^+ released via respiratory unit is coupled with (II) ATPases along with various antiporters: (III) solute symporters (IV), Multiple resistance and pH antiporter (V), and presence of acidic content (VI)

THERMOPHILES

- **Structural Adaptations**
  - Lipid Bilayer Structure
- **Cellular Adaptations**
  - Molecular Chaperones
  - Histone-like DNA Binding Proteins
- **Molecular Adaptations**
  - Excess glutamate, valine, tyrosine, & proline residues
  - Salt-bridges, packing density etc.

HALOPHILES

- **Structural Adaptations**
  - Lipid Bilayer Structure
- **Cellular Adaptations**
  - Salt-in Cytoplasm Strategy
  - Compatible Solute Strategy
- **Molecular Adaptations**
  - Excess acidic amino acids on protein surface

Combination

Halothermophiles

Do they exist, than their limits to life??

What Adaptation Strategies??

What Adaptation mechanisms??

Surviving the Extremes

Extremophiles Can Survive:

- 113 to 200 °C
- - 15 °C
- pH < 0.0
- pH > 11
- 1200 atmospheres
- 0% oxygen
- 20-40 million years dormancy
- 2 1/2 years in space, etc.

EXTREME PROKARYOTES

Hyperthermophiles

HYPERTHERMOPHILES at the base of the tree of Life

Eubacteria:

Aquifex pyrophilus	85° C
Thermotoga maritima	80° C

Archaebacteria:

Acidianus infernus	88° C
Pyrodictium abyssi	105° C
Pyrococcus furiosus	100° C

DATA FROM STETTER (1994)

-Members of domains Bacteria and Archaea

-Held by many scientists to have been the earliest organisms

-Early earth was excessively hot, so these organisms would have been able to survive

Morphology of Hyperthermophiles

-Heat stable proteins that have more hydrophobic interiors, which prevents unfolding or denaturation at higher temperatures

-Have chaperonin proteins that maintain folding

-Monolayer membranes of dibiphytanyl tetraethers, consisting of saturated fatty acids which confer rigidity, preventing them from being degraded in high temperatures

-Have a variety of DNA-preserving substances that reduce mutations and damage to nucleic acids, such as reverse DNA gyrase and Sac7d

-They can live without sunlight or organic carbon as food, and instead survive on sulfur, hydrogen, and other materials that other organisms cannot metabolize

The red on these rocks is produced by *Sulfolobus solfataricus*, near Naples, Italy

Deep Sea Extremophiles

A **black smoker, a** submarine hot spring, which can reach 518- 716°F (270-380°C)

The **deep-sea floor** and **hydrothermal vents** involve the following conditions:

low temperatures (2-3º C) – where only **psychrophiles** are present

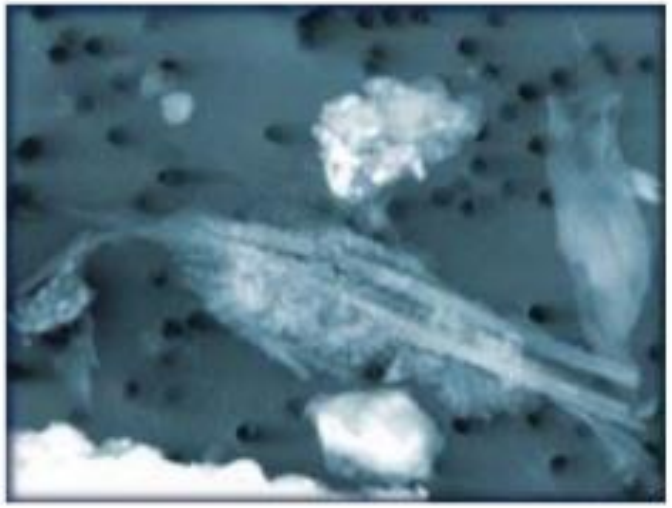
low nutrient levels – where only **oligotrophs** present

high pressures – which increase at the rate of 1 atm for every 10 meters in depth (as we have learned, increased pressure leads to decreased enzyme-substrate binding)

barotolerant microorganisms live at 1000-4000 meters

barophilic microorganisms live at depths greater than 4000 meters

Psychrophiles



Some microorganisms thrive in temperatures well below the freezing point of water, such as in Antarctica

Some researchers believe that psychrophiles live in conditions mirroring those found on Mars

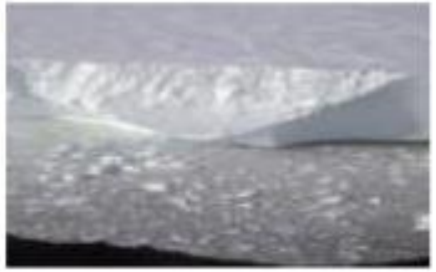
Psychrophiles possess:

-proteins rich in α-helices and polar groups which allow for greater flexibility

-“antifreeze proteins” that maintain liquid intracellular conditions by lowering freezing points of other biomolecules

-membranes that are more fluid, containing unsaturated *cis*-fatty acids which help to prevent freezing

-active transport at lower temperatures



Halophiles

The vivid red brine (teaming with halophilic archaebacteria) of Owens Lake contrasts sharply with the gleaming white deposits of soda ash (sodium carbonate). The picturesque Inyo Range can be seen in the distance.

-Divided into mild (1-6%NaCl), moderate (6-15%NaCl), and extreme (15-30%NaCl)

-Halophiles are mostly obligate aerobic archaea

How do halophiles survive high salt concentrations?
-by interacting more strongly with water such as using more negatively charged amino acids in key structures
-by making many small proteins inside the cell, and these, then, compete for the water
-and by accumulating high levels of salt in the cell in order to outweigh the salt outside

Deinococcus radiodurans

The Radiation Resistor

-Possesses extreme resistance to up to 4 million rad of radiation, genotoxic chemicals (those that harm DNA), oxidative damage from peroxides/superoxides, high levels of ionizing and ultraviolet radiation, and dehydration

-It has from four to ten DNA molecules compared to only one for most other bacteria

-Contains many DNA repair enzymes, such as RecA, which matches the shattered pieces of DNA and splices them back together. During these repairs, cell-building activities are shut off and the broken DNA pieces are kept in place

Eukaryotes

- *Mucor racemosus*
- *Urotricha*
- *Dunaliella acidophila*
- *Philodina roseola*

- Acidophiles are acid-loving microbes. Most natural environments on the earth are essentially neutral, having pH values between five and nine.

- Acidophiles thrive in the rare habitats having a pH below five.

- Highly acidic environments can result naturally from geochemical activities (such as the production of sulfurous gases in hydrothermal vents and some hot springs) and from the metabolic activities of certain acidophiles themselves.

- Acidophiles are also found in the debris left over from coal mining.

- Interestingly, acid-loving extremophiles cannot tolerate great acidity inside their cells, where it would destroy such important molecules as DNA.

- They survive by keeping the acid out. But the defensive molecules that provide this protection, as well as others that come into contact with the environment, must be able to operate in extreme acidity. Indeed, extremozymes that are able to work at a pH below one--more acidic than even vinegar or stomach fluids--have been isolated from the cell wall and underlying cell membrane of some acidophiles.

MECHANISMS OF ADAPTATION TO ACIDIC ENVIRONMENTS

- Most acidophile organisms have evolved extremely efficient mechanisms to pump protons out of the intracellular space in order to keep the cytoplasm at or near neutral pH.
- Therefore, intracellular proteins do not need to develop acid stability through evolution. However, other acidophiles, such as *Acetobacter aceti*, have an acidified cytoplasm which forces nearly all proteins in the genome to evolve ACID stability.
- For this reason, *Acetobacter aceti* has become a valuable resource for understanding the mechanisms by which proteins can attain acid stability.
- Studies of proteins adapted to low pH have revealed a few general mechanisms by which proteins can achieve acid stability.
- In most acid stable proteins (such as pepsin and the soxF protein from *Sulpholobus acidocaldarius*), there is an over abundance of acidic residues which minimizes low pH destabilization induced by a buildup of positive charge.

ALKALIPHILES

- Alkaliphiles are microorganisms that grow optimally or very well at pH values above 9, often between 10 and 12, but cannot grow or grow slowly at the near-neutral pH value of 6.5.

- **Alkaliphiles** are a class of extremophilic microbes capable of survival in alkaline (pH roughly 8.5-11) environments, growing optimally around a pH of 10.

- These bacteria can be further categorized as obligate alkaliphiles (those that require high pH to survive), facultative alkaliphiles (those able to survive in high pH, but also grow under normal conditions) and haloalkaliphiles (those that require high salt content to survive).

- Microbial growth in alkaline conditions presents several complications to normal biochemical activity and reproduction, as high pH is detrimental to normal cellular processes.

- For example, alkalinity can lead to denaturation of DNA, instability of the plasma membrane and inactivation of cytosolic enzymes, as well as other unfavorable physiological changes.

- Thus, to adequately circumvent these obstacles, alkaliphiles must either possess specific cellular machinery that works best in the alkaline range, or they must have methods of acidifying the cytosol in relation to the extracellular environment.

- Many different taxa are represented among the alkaliphiles, including prokaryotes (aerobic bacteria belonging to the genera *Bacillus*, *Micrococcus*, *Pseudomonas*, and *Streptomyces*;

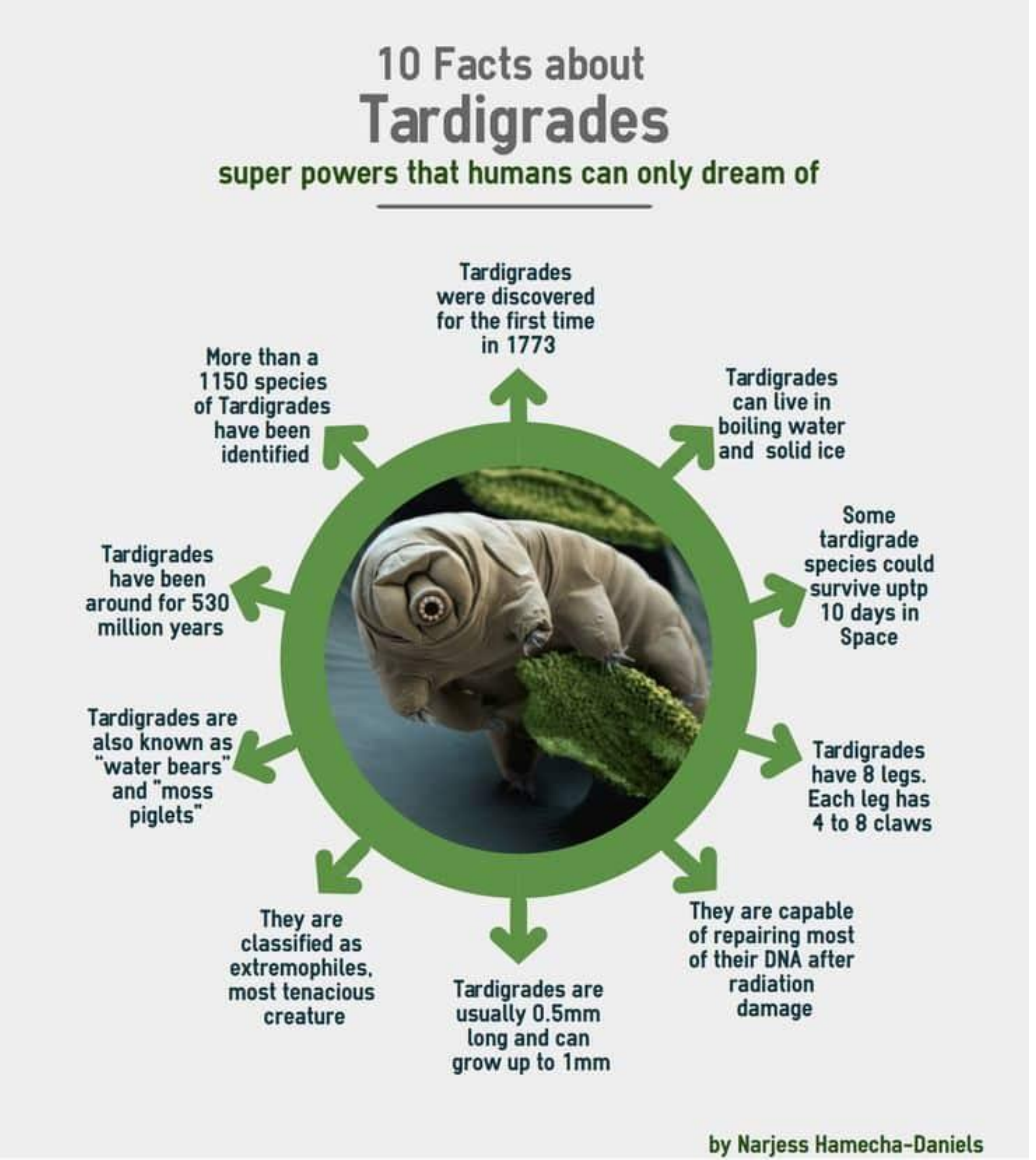
- Anaerobic bacteria from the genera *Amphibacillus*, *Clostridium*; Halophilic archaea belonging to the genera *Halorubrum*, *Natrialba*, *Natronomonas*, and *Natronorubrum*; Methanogenic archaea from the genus *Methanohalophilus*

MECHANISMS OF CYTOSOLIC ACIDIFICATION

- Alkaliphiles maintain cytosolic acidification through both passive and active means.
- In passive acidification, it has been proposed that cell walls contain acidic polymers composed of residues such as galacturonic acid, gluconic acid, glutamic acid, aspartic acid, and phosphoric acid.
- Together, these residues form an acidic matrix that helps protect the plasma membrane from alkaline conditions by preventing the entry of hydroxide ions, and allowing for the uptake of sodium and hydronium ions.
- In addition, the peptidoglycan in alkaliphilic *B. subtilis* has been observed to contain higher levels of hexosamines and amino acids as compared to its neutrophilic counterpart.
- When alkaliphiles lose these acidic residues in the form of induced mutations, it has been shown that their ability to grow in alkaline conditions is severely hindered.
- To survive alkaliphiles maintain a relatively low alkaline level of about 8 pH inside their cells by constantly pumping hydrogen ions (H^+) in the form of hydronium (H_3O) across their cell membranes into their cytoplasm.

Tardigrades, known colloquially as water bears or moss piglets, are a phylum of eight-legged segmented micro-animals.

They are considered to be close relatives of arthropods (e.g., insects, crustaceans). Tardigrades are mostly about 1 mm (0.04 inch) or less in size. They live in a variety of habitats worldwide: in damp moss, on flowering plants, in sand, in fresh water, and in the sea



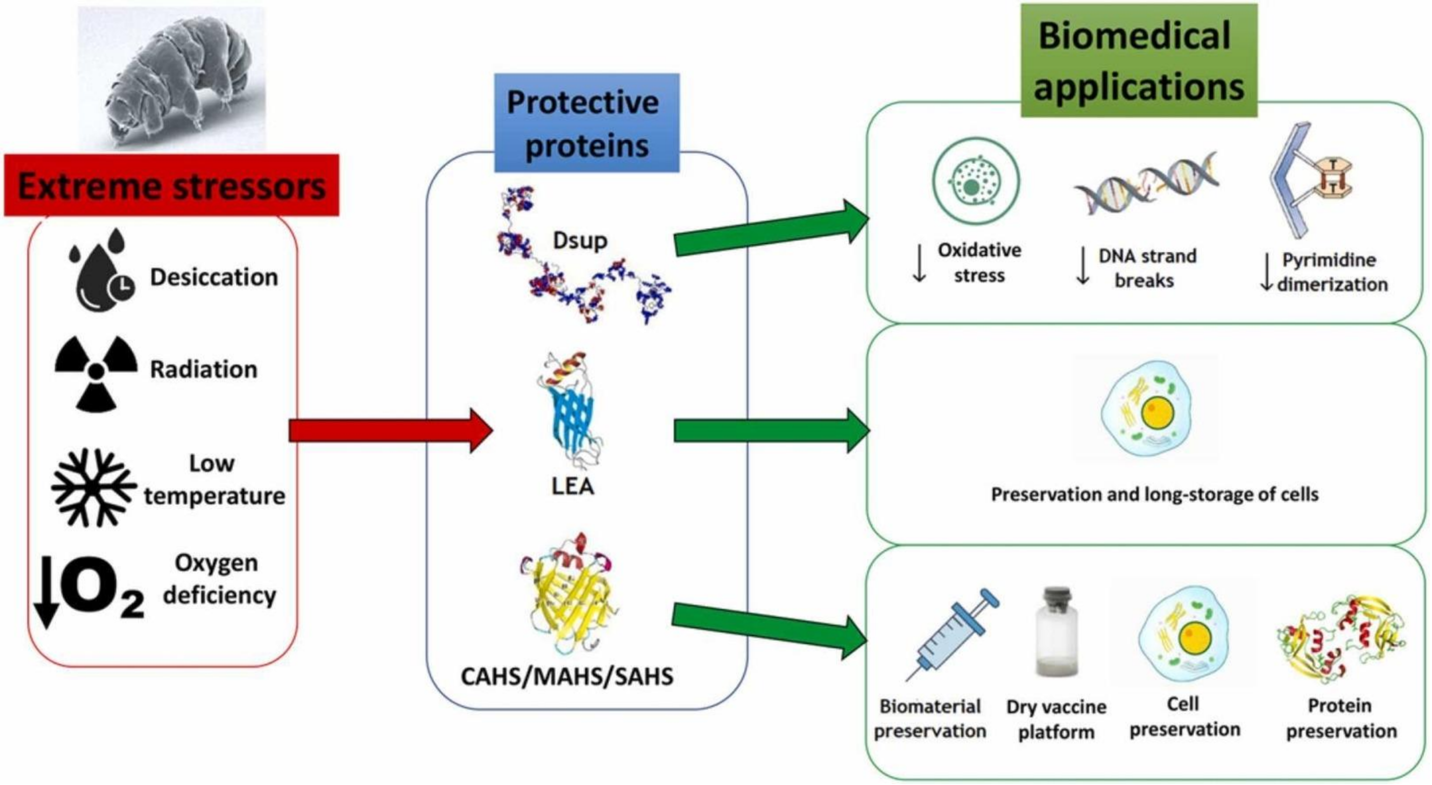


Table 1. Potential applications of tardigrade molecules in biomedicine and pharmacology.

Group of proteins   Potential biomedical applications
Tardigrade disordered proteins
Dsup   Protection from oxidative stress
Protection from radiation
CAHS   Preservation of enzymes
Preservation of cells
Preservation of therapeutic proteins
Novel anti-apoptotic agents
Designing dry vaccine platforms
MAHS   Preservation of cells
Late embryogenesis-abundant
proteins   Preservation and long-storage of cells

The damage suppressor protein (Dsup)

Late Embryogenesis-Abundant (LEA)