Great Salt Lake Halophilic Archaea as a Model For Possible Extant Life on Mars

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Abstract

Expansive evaporite mineral deposits and other geological features on Mars are evidence of ancient lacustrine systems before the planet experienced global climatic change (~3.5 Ga). On Mars, as the surface water dried up, hypersaline lakes would have filled the ancient lake basins. On Earth, the Bonneville Basin, in the western United States, tells a similar story in a more recent timeframe. Today, the bottom of this basin is the modern Great Salt Lake (GSL) and the Bonneville Salt Flats. Evaporation of this freshwater lake left large evaporitic mineral deposits that continually supply salt to modern GSL. Parts of the lake are at salt saturation due to shrinking shorelines and human intervention, and it is here that haloarchaea thrive. The current Martian ultraviolet flux, magnetosphere, lack of tectonic activity, and desiccation suggests that continued life would be challenging. However, microorganisms such as GSL haloarchaea may resist these extreme conditions, especially if entombed in minerals. We propose GSL haloarchaea as excellent analogues for life that could have been in hypersaline lakes on Mars and may remain preserved in the evaporitic minerals there.

Haloarchaea Superpowers

Adaptations to low temperatures (Psychrophillic Haloarchea)

- A Halobacterium species, were recovered from a Deep Lake in Antarctica, a hypersaline ecosystem that does not freeze up to temperatures of −20◦C due to the high salinity.[1]
- Cold temperature survival may be the result of the unusual adaptation allowing the synthesis of unsaturated diether lipids.[2]

Energy generation and nutrient obtainment while dormant

- Some haloarchaea species utilize the trans-membrane protein-carotenoid complex to capture light energy and pump protons across the membrane, generating ATP.[3]
- Haloarchaea can grow in the presence of high concentrations of perchlorate (abundant on the Martian surface) and use the substrate as an electron acceptor for anaerobic respiration.[4]
- Polyploidy could provide nutrients, acting as a phosphorus storage polymer and some species may degrade the extra DNA inside the cell for nutrient obtainment.[4-6]
- The brine in mineral fluid inclusions would contain all material from the solution and would contain to the necro mass nutrients of microbes which have died in the fluid and any larger detritus lodged in the salt crust.[7,8]

Low Water Activity

- During extended dry periods, haloarchaea in GSL can survive despite a water activity so low, most cells would perish.
- Most prokaryotes cannot grow below an a_w value of 0.900.[9-12]
- Researchers observed several haloarchaea species with a_w measurements between 0.687-0.728.[13]
- Archaea cell walls are composed of glycogen instead of a peptidoglycan-outer membrane network that contains an excess of acidic amino acids (glutamic acid, aspartic acid and sometimes sulfate anions) suggesting a hydration shell surrounding the cell may allowing for nutrient import.[14-16]
- Haloarchaea adjust intracellular fluids to be compatible with the external salt water by pumping out Na+ in exchange for K+ in response to the electrochemical gradient.[16]
- Chemotaxis may enable entombment in minerals, as lake water dries, by allowing cells to swim towards the fluid as the mineral lattice is forming.
- GSL haloarchaea species, using holographic microscopy, have been found to have a ten-fold higher efficiency in chemotaxis than the average computed for bacterial model systems.[17]

Category	Strategy	Category	Strategy
DNA Repair	Nucleotide Excision Repair	**Space Conditions**	Exposure to space
	Photoreactivation		Freeze-thaw cycles
	Base Excision Repair	**Lifestyle flexibility**	Use of light energy
	Homologous Repair		Anaerobic growth
Long-term survival	Mineral entombment		Cold temperatures
	Chemotaxis and motility		Warm temperatures
	DNA as a nutrient		Alkaline pH
	Necromass as a nutrient		Perchlorate reduction
	Algal glycerol as a nutrient	**Osmophily**	Growth in low a_w
Radiation resistance	UV resistance		Cell morphology
	IR Resistance		Cell wall structure
	Carotenoid pigments		Protein aa composition
	Bipyrimidine limitation		Potassium accumulation
	Polyploidy		Compatible Solutes

Table 1: Haloarchaea **superpowers**; survival strategies for life at high salinity. These strategies are listed by categories in order to consider each challenge separately though some cellular mechanisms may overlap

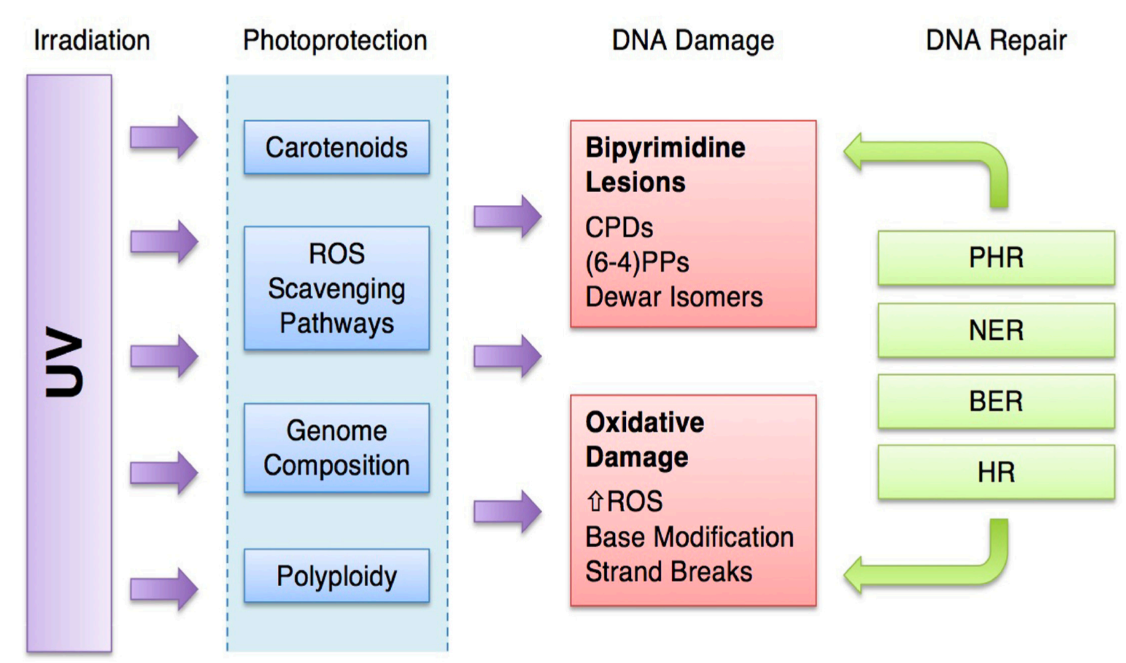

Figure 1

Figure 2

UV resistance and DNA repair

- UV creation of radical oxygen species (**ROS**), repaired by Nucleotide Excision Repair (**NER**) or base excision repair (**BER**) that can fix oxidative base lesions and single-strand breaks. Genomic signatures that feature bipyrimidine limitations, which ameliorate the cyclization of most susceptible adjacent pyrimidine nucleotides (5' to 3,' TC then TT) when exposed to high UV.[18]
- Haloarchaea are typically highly polyploid, a simple but effective strategy for protecting genes by duplication.[19-18]
- Photoreactivation (**PHR**) can repair UV-induced photoproducts in DNA directly The homologous recombination (**HR**) pathway repairs double-strand breaks in DNA simultaneously through exonuclease resection and subsequent ligation of broken ends.[21-25]
- Carotenoid pigments (fig 2) of haloarchaea prevent damage to DNA and other cellular components from **ROS** created by photons of light from the UV.[26-28]

Figure 3: a) Bonneville Salt Flats in the Great Salt Lake desert Image credit: Ken Krahulec, Utah Geologic Survey. b) Sedimentary rocks in the foreground of Mount Sharp, near Gale Crater, Mars, as imaged by the Curiosity rover (Sol 548, 2014). Image credit: Marco Di Lorenzo and Ken Kremer, NASA/JPL, public domain.

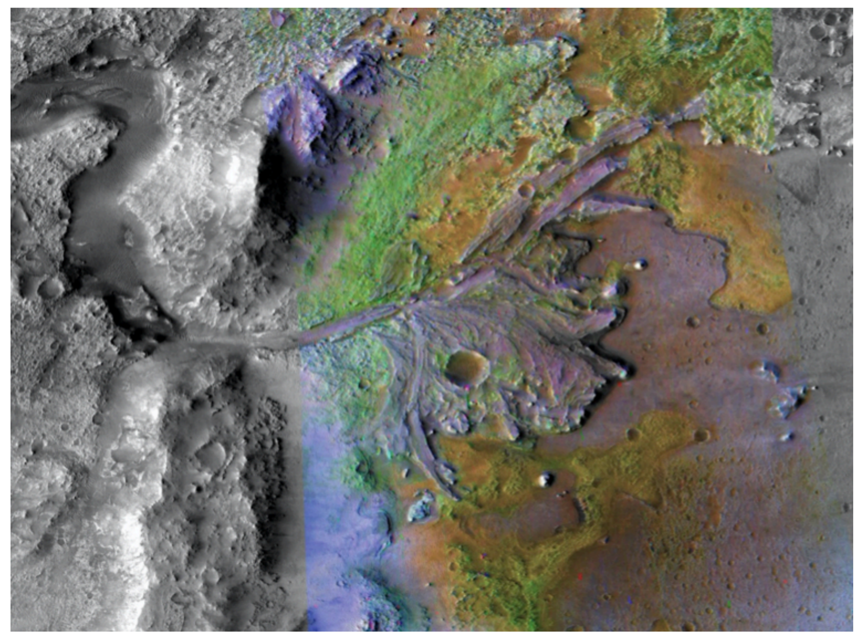

Figure 4: Landing site of NASA's Mars 2020 rover mission, Jezero Crater, as imaged by the Mars Reconnaisance Orbiter. The green coloration shows hydrated sulfate minerals (e.g. gypsum) at the site of an ancient river delta, suggesting evaporite formation.

Model of Extant Life

- It has been recognized for some time that the disappearance of surface water, billions of years ago, on Mars during global climatic change would have resulted in a phase of hypersaline liquid water, and that if life were there, it would be halophilic.[29,30]
- What we know of life on our planet exists where water exists in liquid form and that salt has not been an obstacle.
- Our best guess for potential extant life on Mars would be microorganisms' alike extremophiles on Earth that can handle low water activity with aplomb, the haloarchaea.
- It is also a reasonable speculation that these organisms may have lost the hypersaline lakes they once swam in during better conditions for life on Mars.
- On Mars, sites where evaporite minerals could have been periodically subjected to dissolution and re-evaporation may feature evaporite-entombed haloarchaea communities that are more diverse than those found in ancient fluid inclusions left undisturbed over the entire geologic time period.[31,32]

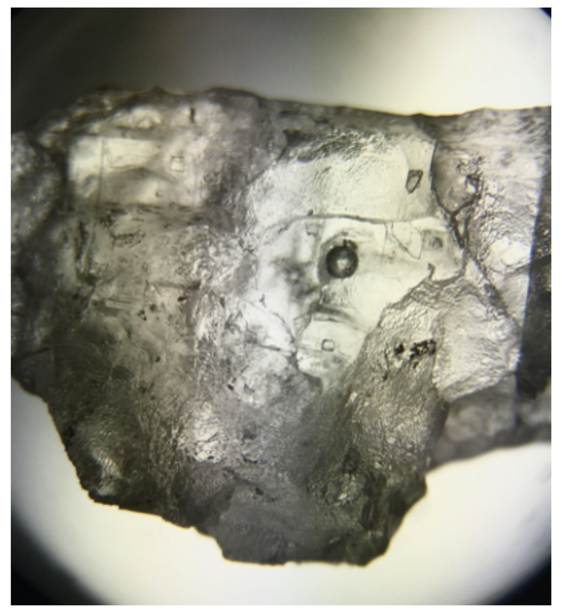

Figure 5: Fluid inclusions are visible inside halite crystal marked by a bubble in the sequestered brine, scale bar is 0.5 cm. (Image credit: Adrik DaSilva)

Conclusions and Insights

- Haloarchaea are likely candidates for extant life based off the superpowers mentioned in this poster.
- Earth's analogue sites to Martian lacustrine systems can help us envision the evolution of microbial life on the red planet. Martian evaporite minerals on the surface and near-subsurface are accessible to rovers for in situ analyses, making these sites a priority for Mars missions using existing instrumentation.
- Studies of Earth hypersaline lakes, such as GSL, indicate they are all declining in elevation, and thus it is an opportune time to understand what happened on Mars, especially concerning potential aquatic life, as water became more saline and eventually dried into mineral deposits.[33]
- Life detection methods should take the biochemistry of said environment into consideration instead of looking for a particular biochemical definition of life when we look to Mars, we necessarily use our abundant knowledge of Earth life, and we inquire regarding which life form from Earth might best survive on the Red Planet, and where might we find them?

References