Early Evolution of Haloarchaeal Photopigments and Potential as a Remote Surface Biosignature

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Haloarchaea are widely distributed in hypersaline environments and display novel pigments resulting in unique biosignatures on Earth. The brightest pigments observed in haloarchaeal blooms are derived from isoprenoid compounds and include retinal and other carotenoids, which are synthesized by a branch of the pathway leading to archaeal membrane lipids. Retinal is the chromophore in bacteriorhodopsin (BR), a light-driven ion pump in the purple membrane of haloarchaea. The proton gradient generated by BR, a prototype of integral membrane proteins, is coupled to ATP synthesis, which constitutes one of the simplest phototrophic systems on Earth. Similar retinal-based ion pumps (e.g. proteorhodopsin) are also common in planktonic bacteria in the oceans. While the evolutionary history of these retinal pigments is unclear, we have proposed that appearance of such a simple phototrophic energy transduction system may have predated the onset of oxygenic photosynthesis and the rise of oxygen in the atmosphere about 2.3 billion years ago. Our hypothesis is based partly on the observation that the chlorophyll pigments responsible for oxygenic photosynthesis lack appreciable absorption at wavelengths around 500-600 nm, an energy-rich region of the solar spectrum, where the simpler retinal-based light-harvesting systems exhibit a strong well-defined peak of absorbance. The complementary spectra of retinal and chlorophyll pigments suggested a scenario when lifeforms with simple retinal-based light-harvesting systems dominated prior to the development of modern chlorophyll-based life. Retinal-based photopigments would produce surface biosignatures distinct from that of the vegetation 'red-edge.' Indeed, hypersaline lakes with blooms of modern haloarchaea do show a strong increasing brightness trend from ~500 nm to a ~680 nm peak; water absorption is significant at longer wavelengths. Furthermore, retinal-based analogs to modern terrestrial vegetation, with no overlying water, would produce a 'green edge' near 550 nm. These features are within the wavelength sensitivity window of planned next-generation space-based telescopes capable of directly imaging exoplanets and should be considered in the search for life elsewhere.