Some Like it Hot: Astrobiology and Extremophilic Life

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Though there were a multitude of intervals of time before us, we can barely imagine the immensity of our very own Earth's history because the presence of humans only occupies a fraction of that time. Fossil records aid in understanding what came before us, including dinosaurs, trilobites, and ancient microbial life, and what we learn from these applies to the commencement of life on Earth. The pattern of life's origin on Earth may subsequently apply to other planets in other galaxies and star systems in profoundly beneficial ways. Thus, understanding the vast range of environments within our own planet is a wonderful place to start exploring.

Though there are a variety of environments where life can survive, humans are limited to the troposphere—the lowest atmospheric layer—and have adapted to varied climates and elevations within this expanse. Oxygen, relative temperatures, and pressure are among the requirements for humans to survive. In stark contrast to these requirements for human life, consider the *extremophiles*, organisms that thrive in extreme conditions. They are typically unicellular prokaryotes—either bacteria or archaea. In relation to what we know of the vast majority of life on our planet, they are the rule breakers. Some of these organisms do not need carbon beyond carbon dioxide, and can survive without oxygen or even the relatively mild temperatures of Earth as we experience them. Still, from the perspective of the extremophilic organism, their environment is completely normal. This paper will explore their extreme character, as it may lead to clues about how we can conceptualize life beyond our present realm.

Understanding extremophiles is something that is pertinent not only to realizing life's variety and splendor within the territory of our planet, but their abilities are imperative to the search for life beyond Earth—and even beyond our own star system. This range includes the unbearably hot temperatures (i.e. to human standards) of the inner terrestrial planets of the solar system, to the much colder outer reaches in the moons of Saturn and Jupiter. To commence our understanding, we must know where these organisms have thrived and lived; thermophilic, heat-loving, life is naturally found in deep-sea thermal vent environments (Frontiers, 1997) and in the Hot Springs of Yellowstone National Park (Stahl et al, 1985; Barns and Burggraf, 1997; Spear, 2005).

The properties of extremophiles are interestingly not the same among all in this extreme-loving class—they have adapted to *their* environment. It has become increasingly clear that life has modified to and thrived in amazing places: nutritionally limited environments, under high pressure, and astoundingly high temperatures. Still, there are strong indices for life in places we have not even discovered yet. We have learned that some extremophiles die when brought to so-called normal temperatures "because their enzymes have evolved to function only at the high temperatures at which they live," (Bennett et al 2002) but this is notably not a necessary characteristic of all extremophilic life because of its variety.

Almost 20 years ago, everyone seemed to accept that nature could only harbor life on the thin covering of Earth's surface because of the necessity of sunlight, but since then this view has changed. In the late 1980s, researchers found microbes living in rock 500 meters below the surface in South Carolina (Monastersky, 1997). We have since pushed the known threshold much deeper, and "microbes have apparently remained prisoners of the deep for millions of years, making such colonies veritable living fossils."(Monastersky, 1997) This discovery certainly pushed the envelope of life deeper, but it also sets the stage for inquiry.

The *heated* debate over the origin of life produces various models that either revise or completely disagree with other theories. One current theory is that life originated deep beneath the surface of the ocean in hydrothermal vents. Since the discovery of hyperthermophilic life in hydrothermal fluids recovered from "smoker" vents on the East Pacific Rise, Lilley Baross and Jody Deming have studied the widely accepted upper temperature limit for life. They have revealed that the temperature at which the hyperthermophilic organisms thrive is approximately 300 degrees Farenheit and possibly beyond (Frontiers 1997). Many microbiologists are even willing to speculate that the maximum may above this limit. These boiling volcanic vents on the ocean floor may have provided the nutrients and conditions required for life to begin, but under truly intense pressure and heat. The supporters of the thermal vent theory will argue that the deep oceans of the early earth would have sheltered early microbial life. The microorganisms may also have adapted to the heat from the period of heavy bombardment about 65.5 million years ago, the K-T event. Even so, this thermal vent theory is among a myriad of other beliefs that try to distinguish the most plausible scientific explanation of the origin of life. Whatever the origin of life was, we need to examine where it may have begun to understand the amazing variety as we see today.

Theories for the evolution of life were not invented by Charles Darwin, but rather were solidified by his voyage to the Galapagos on the HMS Beagle, and his book *The Origin of* Species. He proposed the mechanism of natural selection to explain his observations of the finches and other species on the islands. Darwinian states, "if it could be demonstrated that any complex organ existed, which could not have been formed by numerous, successive, slight modifications, my theory would absolutely break down" (Origin of Species, 1859). Following this logic, it is plausible that certain bacteria have adapted to extreme environments.

Every environment produces challenges that an organism must meet in order to survive. In 1996, Enrique Querol and his colleagues reviewed the protein structural modifications for life at temperature extremes. They demonstrated that the amino acid sequence of a protein in thermostable and mesostable isoproteins relate to changes in structure, stability, and function. With close examination of previous research, they questioned "simplistic" explanations and that "eight of the replacements in β-strands would accomplish

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enhanced thermal stability upon stabilizing their strand dipoles."(Querol et al, 1996). As thermophilic microorganisms are not able to shield their cellular components from the environment, they have adapted to maintain their structural integrity. The study by Querol is one attempt to explain such adaptations.

Extremophiles living near smoking and sulfur-rich ocean floor vents are not easily sampled. Yet, an article reviewing the work of Biochemist Mike Adams described his extensive work with organisms in this territory (Hivley, 1993). These organisms have a love for heat, and "that sets them apart from all other life. At 212 degrees Fahrenheit, the molecules that we're made of—that all life as we know it are made of—fall apart. DNA comes unglued, and proteins collaps[e] in a tangled heap, usually within seconds" (Hively, 1993). So, it is staggering that some extremophiles thrive at such unsympathetic temperatures. Even 16 years ago, it was accepted that as we grow in our understanding of these organisms, they had the promise of revolutionizing ideas on the very chemistry and origins of life in profound ways.

Specifically, Adams studied the bacterial enzyme *hydrogenase*, which can strip water molecules of hydrogen. Adams read the reports of German Microbiologist Karl Stetter who "in 1982 discovered the first organisms that thrive above 212 degrees, in shallow hot springs off the coast of Sicily. Later, he and other researchers began finding them in vents up to three miles deep at the bottom of the ocean." (Hively, 1993). From these reports, Adams ordered cultures from both thermophilic organisms, and found that they had a "superhot" version of the enzyme *hydrogenase*. Through this finding and a subsequent series of tests, Adams found metals in the hyperthermophilic organisms when attempting to isolate the enzyme. Tungsten, an especially rare element, was discovered in this isolation process. The organisms thrived on this element, but most importantly, tungsten induced minor changes in protein structure which gave "dramatic changes in stability" because of allowances in enhanced enzyme flexibility over evolutionary history (Hively, 1993).

The volcanic hot springs of Yellowstone National Park are studied at present, and resaerch by Spear, Walker, McCollom and Pace (2005) gave special attention to this geothermal microbial ecosystem as a whole. The brilliant colors of the hot springs and geysers at Yellowstone range from brilliant orange, blue, red, and yellow, to green. As we marvel at these hues, we may also imagine how such amazingly adapted creatures would live inside pools like these—on another hot planet. We are discovering *new* news about exoplanets and characteristics of planetary bodies on a nearly daily basis as science progresses. What we are learning about our galaxy and planetary neighbors can be utilized with the knowledge accumulating about extreme microorganisms.

The accumulating discoveries are answering many questions, but also raising more. Are there or have there ever been extremophiles on Mars? Or on Jupiter's moon, Europa? Recently discovered was a plume of icy water from Saturn's moon Enceladus: "Detected last year by the Cassini probe orbiting Saturn, the plume opens up the possibility that icy moons considered uninhabitable may actually harbor water, and life" (Figure 1; Vergano, 2006). A current project is "Icepick: the Europa Ocean Explorer," which is an effort to create a plan for a future mission; the spacecraft "would explore the liquid water oceans that may exist beneath Europa's surface" (Figure 2; Icepick, 2006). To think of such grand-scale projects may seem far-fetched, but with the accumulating literature on extremophiles, the prospects look all but grim.

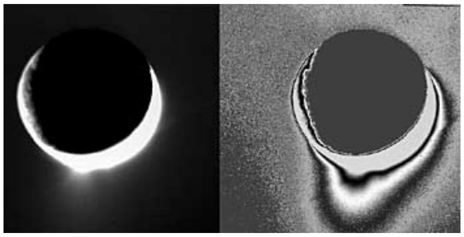

Figure 1. Plumes of icy material extends above the southern polar region of Saturn's moon Enceladus. Courtesy of NASA, JPL, Space Science Institute via AP.

Figure 2. Icepick: the Europa Ocean Explorer project

It is important that we, as humans, are reminded that our world contains spectacularly diverse forms of life. Lessons gleaned from studying the extremophilic life on Earth are applicable elsewhere in the solar system. The collaborative efforts of science will enhance our understanding of life here on Earth, and subsequent theories may be generated from this knowledge for life's existence elsewhere. We may look forward to journeys managed quite different from, but with the same spirit of over a century ago in Jules Verne's novel: *A Journey to the Center of the Earth*. The ways which humans are exploring the depths and high temperatures of the Earth today will apply to the missions beyond it, tomorrow.

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