Biodata of **Joseph Seckbach**, author of "***Life on the Edge and Astrobiology: Who Is Who in the Polyextremophiles World?***"

Professor Joseph Seckbach is the founder and chief editor of ***Cellular Origins, Life in Extreme Habitats and Astrobiology*** ("COLE") book series. He earned his M.Sc. and Ph.D. from the University of Chicago (1963, 1965, respectively) and did a postdoctoral training at Caltech, Pasadena, CA, and led a group at UCLA on search for extraterrestrial life. Dr. Seckbach is currently retired from the Hebrew University (Jerusalem, Israel). Beyond editing >30 books (for Springer and other publications), he published scientific articles (on phytoferritin, thermoacidophilic algae, origin of life, etc.). He authored (with R. Ikan) the Hebrew chemistry lexicon and edited and translated several popular books. His recent interest is in life in extreme environments and in astrobiology.

E-mail: **joseph.seckbach@mail. huji.ac.il**

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LIFE ON THE EDGE AND ASTROBIOLOGY: WHO IS WHO IN THE POLYEXTREMOPHILES WORLD?

JOSEPH SECKBACH
The Hebrew University of Jerusalem, Jerusalem, Israel

1. Introduction

Life exists in almost every ecological niche on Earth, and the majority of living organisms thrive in “normal” or “common” conditions. These are the environments that we are familiar with from our daily life. The organisms distributed under those conditions are at moderate temperature (5 to ~40 °C), 1 atm sea level pressure, with our known gas compositions, and oxygen rich atmosphere, close to neutral pH level. We consider these conditions as benign ambient habitats.

There are, however, also on land or below Earth’s surface organisms dwelling at the edge of the “normal” limits for life. These creatures exist under very severe (from our anthropocentric point of view) environmental conditions. We refer to these hardy organisms as extremophiles (Rothschild, 2007; Seckbach, 1999, 2000, 2007, 2012; Stojanovi et al., 2008). Among the extremophiles are unicellular and multicellular organisms. The many microbes thriving under multiple forms of stress are termed polyextremophiles (in this volume). These creatures include, among others, the hyperthermophiles at acidic (low pH) conditions or hypersalinity conditions with high UV radiation levels and high pressures at the bottom of the ocean with low/high temperatures. Harboring around the hydrothermal chimney vents are communities of microbial and multicellular organisms at elevated pressure, temperature, and acidic pH. Among the higher animals there are clams, mussels, tubeworms, and a variety of grazers (Islam and Schulze-Makuch, 2007). Let us look briefly at the organisms living in these severe conditions.

2. The Extremophiles

In this category, we include both autotrophic and heterotrophic microorganisms, prokaryotes, and to a lesser extent eukaryotic or multicellular representatives. A comparative table of oxygenic photosynthesis of prokaryotes and eukaryotes in extreme environments has recently been presented (Seckbach and Oren, 2007). Extreme environments exhibit a relatively lower biodiversity in which the organisms show a high adaptation capacity. These microbes are living in a severe conditions of life, such as at high/low pH ranges or at high/low scales of temperature levels, high salinity (up to saturated salt solutions), in alkaline waters or soil (such as soda lakes), acidic sulfur-rich areas, and high pressures (at terrestrial subsurface or living in great depths of oceans). Some of the organisms live with low water activity, for example, osmophiles and xerophiles, while others may thrive with low nutrients or tolerate heavy and toxic metals. Among these organisms are bacteria, archaea, eukaryotes including algae, and other protistans, unicellular and multicellular, lichens, fungi, plants, and invertebrate animals. Extreme environments are considered hostile and even deadly to "common" forms of life (mesophiles), while most extremophiles themselves are not able to live under mesophilic conditions.

Large amounts of biomass reside in the subsurface of the Earth, and communities of microorganisms have been observed under the surface. These organisms live without light, at elevated temperatures, and under high pressure. The extremophiles may well be models and analogues for extraterrestrial life (Seckbach and Chela-Flores, 2012).

2.1. CATEGORIES OF THE EXTREMOPHILES

Extremophilic organisms can tolerate very harsh conditions such as:

High temperature (thermophiles to hyperthermophiles, 40–115 °C and even higher up to 122 °C at the hydrothermal vents under high pressure (Stan-Lotter, 2012; Stetter, 2006; Takai et al., 2008)). An older publication by Baross and Deming (1983) reported that thermophilic marine bacteria isolated from the vicinity of a submarine hot spring grow at temperatures up to at least 250 °C at 265 atm. However, no other source could confirm that super heat value. On the other temperature scale, organisms grow at minus 20 °C (for cryophiles/psychrophiles).

Very low pH (−0.5 to 4 pH: acidophiles) or high pH levels (8–12: alkaliphiles).

High salt concentrations (halophiles) up to saturated brines (hyperhalophiles). For example, the green alga *Dunaliella salina* tolerates >5.5 M salt, and another species of *Dunaliella* survives in the Dead Sea, Israel (Giordano and Beardall, 2009).

High hydrostatic pressures (barophiles/piezophiles): maximum pressure reached ~1,100 atm on the ocean floor at a depth of 10,900 m. For every 10 m of water column (towards the deepness), there is a hydrostatic pressure increase of 1 atm. Similarly, barophilic organisms are also in the subsurface of dry land (such as in deep mines).

Environments rich in toxic chemicals: heavy toxic metals such as arsenic (Wolfe-Simon et al., 2011), Cu^{II} (Twiss, 1990), or in Zn^{II} and Cd^{II}.

Moreover, it is known that some bacteria are able to metabolize hydrocarbon compounds from oil spills at the sea surface. Further features of extremophiles are presented in the ensuing.

2.2. HABITATS AND LIVING CONDITIONS OF EXTREMOPHILES

Not only prokaryotes but also several eukaryotic microbes can live under anoxia (Altenbach et al., 2012) and utilize anaerobic metabolism. In addition, some algae are able to thrive under pure CO_2 gaseous stream and show higher growth rates and more oxygen release by photosynthesis than when air is bubbled through the microbial cultures (Seckbach, 1994; Seckbach et al., 1970).

One can observe extremophiles in various harsh habitats, such as in hot springs and other geothermal ecosystems (as found in Yellowstone National Park, USA; Rio Tinto, Spain; or in extreme hypersaline solution in the Dead Sea, Israel; sites in Iceland, south Italy, New Zealand, Japan; and on the floors of the hydrothermal vents in the oceans). The upper limit of (hyper) thermophiles has been determined at 113 °C and possibly up to 121 °C (Stan-Lotter, 2012; Stetter, 2006). There are microbes that live in severe cold areas such as those found in Antarctica and the northern hemisphere. There are microorganisms in the anoxic brine basins in the sea, and endolithic microbial life (Golubic et al., 1981) was observed in Antarctica (de los Ríos et al., 2003). Further information has been published by Stan-Lotter (2012) who presented tables of prokaryotic extremophiles with their tolerance to extreme factors.

2.3. PUBLICATION AND DISTRIBUTION OF EXTREMOPHILES

An early comprehensive survey of eukaryotic extremophiles was published 15 years ago (Roberts, 1998). Of late, some new journals devoted to extremophiles were established, and a number of books and reviews on the topic appeared (Horikoshi and Grant, 1998; Seckbach, 2000, 2012; Rothschild, 2007; Rothschild and Mancinelli, 2001; Rainey and Oren, 2006; Gerday and Glandorf, 2007; Seckbach and Walsh, 2009). International congresses have been organized around the topic of biological extremes.

3. The Polyextremophiles and Early Earth

Organisms that dwell in multiple harsh conditions are common in certain extreme environments. Some of their environments might resemble the conditions that probably occurred on early Earth. The early Earth has been assumed to have been warmer than today, anaerobic, and with higher concentration of CO_2, while the first prokaryotic microorganisms have been assumed to be thermophiles (or thermotolerant), or at least those that survived the late heavy bombardment. Several scientists believe that the origin of life was at the hydrothermal vents at high temperature level (Martin et al., 2008). It is interesting to note that the most deeply rooted microorganisms (in hydrothermal vents at the bottom of the ocean) are thermophiles, suggesting that the earliest common ancestor might have been a thermophilic cell (Stojanovi et al., 2008). The early atmosphere supposedly contained only trace amounts of O_2, at least; the main gases were CO_2, water vapor, H_2S, N_2, methane, and CO (Kasting, 1993). Only with the appearance of the cyanobacteria was the atmosphere oxidized and "poisoned" with their O_2 release via PS_{II} (photosystem II is involved in the light reaction stage of the photosynthesis process of cyanobacteria, algae, and plants. The oxygen is release following the splitting of water). Finally, the oxygen level reached the present level of >20 % in the atmosphere. Hence, the early living organisms which were under the above described as well as post-biotic conditions (pressure, high temperature, anaerobic atmosphere) found niches to survive and thrive in similar environments.

3.1. BIODISTRIBUTION OF EXTREMOPHILES

Some extremophiles live in harsh niches like the Sahara Desert (northern Africa, with high temperature, radiation, and desiccation), the very arid Atacama Desert (Chile), and haloalkaline soda lakes, which represent a unique ecosystem with high pH (up to 11) and salinity, even up to saturation, due to the presence of high concentrations of sodium carbonate in brines. Despite these doubly extreme conditions, most of the lakes are highly productive and contain a fully functional microbial system. Such soda lakes are located in Nevada, California (Mono Lake, Searles Lake), and Egypt at Wadi Natrun (see chapter "Two Centuries of Microbiological Research in the Wadi Natrun, Egypt: A Model System for the Study of the Ecology, Physiology, and Taxonomy of Haloalkaliphilic Microorganisms" by Oren in this volume). Among the organisms living in these lakes are copepods, aquatic insects, unicellular eukaryotic algae, and brine shrimps. The microbial sulfur cycle takes place in most soda lakes. Other extremophiles live in geysers, hot springs, and deep-sea hydrothermal vents. The hypersaline microbes live in high saline places such as in the Dead Sea, Israel (see Oren and Seckbach, 2001), or in Great Salt Lake (Utah, USA). Halotolerant bacteria from Great Salt Plains (GSP) in Oklahoma (USA) grow in high concentrated $MgSO_4$, while others live in saturated salt solution. The barophilic organisms tolerate high pressure and thrive at the bottom of the oceans or in subterranean environments. Among these organisms living in harsh conditions, we find archaea, bacteria, and eukaryotes.

A novel ultramicrobacterium (*Herminiimonas glaciei*) was isolated from a 120,000-year-old Greenland glacial ice core, at a depth of 3,042 m, and successfully revived (Loveland-Curtze et al., 2009). The primitive type of cyanobacterium *Chroococcidiopsis* is capable of surviving in a large variety of extreme conditions, such as dryness, high and low temperature, exceptional aridity, salinity, and other harsh environments. It lives beneath translucent pebbles which act both as a moisture trap and a UV shield (Friedmann and Ocampo-Friedmann, 1995). Likewise, the eukaryotic unicellular acido-thermophilic alga *Cyanidium caldarium*, a red alga (Rhodophyceae), appears as green spherical cells (Seckbach, 1994, 2010;

Castenholz and McDermott, 2010) and thrives in pure CO_2 (Seckbach et al., 1970), at elevated temperatures (57 °C), and in very acidic solutions (pH 0–4). *Cyanidium* culture even tolerates rinsing in 1N H_2SO_4, which is a good method to obtain purified cultures. One genus of this family (Cyanidiaceae), *Galdieria sulphuraria*, thrives in autotrophic and even better in heterotrophic conditions with supply of carbohydrates (Seckbach, 1994). In the harsh conditions of Antarctica grow bacteria and 300 species of algae (such as *Chlamydomonas, Chlorella* and mosses- see Chela-Flores and Seckbach, 2011). In the Dry Valleys of Antarctica, cyanobacteria live inside rocks as endolithic layers. In the snow and ice, as in the Siberian permafrost, Antarctica, and the Arctic zones, are the cryophilic bacteria and algae. Such snow algae may appear with green, yellow, orange, or red coloration and have carotenoids during some periods.

3.2. LONG-LIVED BACTERIA

In 1998, NASA reported that the bacterium *Streptococcus mitis* survived on the surface of the Moon in a camera left almost for ~3 years and then was revived (Mitchell and Ellis, 1971). This demonstrates an additional feature of the ability of microorganisms to tolerate very severe conditions (such as extreme temperatures, UV radiation, and lack of nutrition). Among the UV radiation-resistant microorganisms are the *Deinococcus radiodurans* bacteria (Singh and Gabani, 2011). Cyanobacteria species can live endolithically under the surface, as, for example, the extremophile *Chroococcidiopsis*.

The above facts about organisms tolerating harsh conditions of life might not be too surprising since it is known that bacteria and some toxic microorganisms can be still vital after thousands of years in isolated dryness, such as the Egyptian mummies inside the pyramids. Furthermore, *Bacillus* sp. were revived after 25–30 million years from insects embedded inside amber, while Vreeland et al. (2000) claimed to have isolated and revived a 250 million-year-old halotolerant bacterium from a primary salt crystal (see below).

3.3. EUKARYOTIC LOWER AND HIGHER EXTREMOPHILIC ORGANISMS

Among the eukaryotic extremophiles are algae, fungi, mosses, and lichens. Each lichen is a symbiotic association between a fungus host and cyanobacterium or alga occurring as crusty patches grown on bare ground or tree trunks. They may survive in extreme environments on Earth and in the unprotected conditions of space. They were exposed to space under conditions of vacuum, ultraviolet radiation, and severe cold and survived. They have survived also under simulated conditions of space (de Vera et al., 2003, 2004; Raggio et al., 2011).

3.3.1. Shrimp Beneath Ice and Pompeii Worm

NASA found shrimp 200 m beneath the Antarctic ice where almost no advanced life should be. Among the polyextremophilic invertebrates is the Pompeii worm *Alvinella pompejana*, which is one of the most heat-tolerant animals—up to 105 °C—on Earth (Islam and Schulze-Makuch, 2007). It has been described as a deep-sea polychaete that resides in tubes near hydrothermal vents (black smokers) along the seafloor. This worm has symbiotic relations with chemolithotrophic bacteria that are in a layer on the dorsal body. The worms tolerate high hydrostatic pressure, high temperature, and other stress factors.

3.3.2. Subsurface Nematodes

Mephisto worms—*Halicephalobus mephisto*—are nematodes from the terrestrial deep subsurface of South Africa (Borgonie et al., 2011). These round worms live in gold mines' rocky, ca. 2 km underground. They are 0.5 mm long and exist in low oxygen, their body is soaked, and they live from 1.3 to 3.6 km down in the deepest mine. These nematodes' environment is estimated to be 2,000–12,000 years old. One species survived even the space shuttle Columbia breakup in 2003. They are adapted to tolerate hot temperatures that would kill most of its land-living species. Some were found in hot springs (at elevated temperature of ~55 °C), and they may colonize the most inhospitable habitats such as dry, frozen soils in Antarctic Dry Valleys.

3.3.3. Tardigrades

Tardigrades or water bears (or moss piglets) are even more extraordinary extremophilic organisms—the tardigrades meaning "slow walkers." They are segmented, multicellular animals, mainly aqueous organisms with eight legs and of small size (mostly <1 mm long). They are found in damp pools, in water on lichen and mosses, in acidic solution of algal culture, on soil, and in marine or freshwater sediments. They are classical polyextremophiles and are able to survive in extreme environments. These creatures have the potential to survive travel to other planets because of their tolerance to extreme environmental conditions by means of a dry ametabolic state called cryptobiosis. Their survival capacities in severe conditions are stunning as they tolerate various extreme environments that would kill almost any other animals. Tardigrades tolerate very high and low temperature ranges (180 to −273 °C), 1,000 times more radiation than other animals (they must have a very efficient means of repairing DNA damage after such strong radiation), and survive prolonged periods of drought and almost a decade without water. These animals were exposed to weightlessness, space vacuum, and lashing of both cosmic and solar radiation for 10 days aboard a Russian satellite about 270 km above sea level, and upon return to Earth they were unharmed and continued to reproduce. They tolerate extreme dehydration, freezing temperature, and high pressures in cryptobiosis; they can be dormant for years while needing only a drop of water to revive them. Anhydrobiotic eggs of the tardigrade *Ramazzottius varieornatus* also have a broader temperature resistance compared to hydrated ones (Horikawa et al., 2012). They may be considered as ideal analogues for candidacy for extraterrestrial living. For more sources on these water bears, see Chela-Flores (2011, p. 115) and the relevant references, such as Horikawa (2011), chapter "Tardigrades: An Example of Multicellular Extremophiles" by Schulze-Makuch and Seckbach in this volume.

3.3.4. Ticks Inside the Electrons Stream

The case of Ticks in SEM. Recently it was reported (Ishigaki et al., 2012) that living ticks (*Haemaphysalis flava*) were placed in a vacuum and bombarded by electrons in a SEM (scanning electron microscope). Upon release from the SAM chamber, these animals were still fully alive.

4. Astrobiology

4.1. THE POSSIBILITY FOR EXTREMOPHILES TO LIVE IN EXTRATERRESTRIAL PLACES

Astrobiology is a relatively new branch in the astronomical-biological sciences that seeks (among other tasks) to understand the origin of life and the interrelation of life with environments. It deals also with the question of how life could extend beyond our planet. Akin to Astrobiology is the SETI group (*Search for Extraterrestrial Intelligence*) which tries to find communication with extraterrestrial civilization. In the past, parallel study was termed Exobiology, Bioastronomy, Cosmobiology, and so on.

Astrobiology tries to answer whether life is common or rare in the universe. The Panspermia hypothesis (McNichol and Gordon, 2012; Wickramasinghe, 2012) claims that life in the universe has been spread by spores or bacterial cells from space and developed in a suitable environments as on Earth. One of the prerequisites and priorities for the search of life also beyond Earth is the availability of liquid water, sources of energy, and a supply of organic molecules. These factors are important for cellular metabolism. We know that wherever there is liquid water, there are good chances to find living organisms (Chela-Flores, 2011).

4.1.1. Mars: Our Sister Planet

The investigations about life (or lifelessness) of Mars, Europa (moon of Jupiter), and Enceladus (satellite of Saturn) and Titan (satellite of Saturn), to a lesser extent, are one of the main targets today in the search for extraterrestrial life. The frozen desert of Antarctica resembles the chilled dry world of the Martian surface (2 °C, −65 °C, and 20 to −126 °C) of today (McKay et al., 2012). Several photos by various flybys over Mars as well as rovers rambling over the Martian surface show that in the past (~3.5 billion years ago), this planet was warm and wet with plenty of water. The Red Planet appears to have been sculpted in part by flowing liquid, as by ancient rivers, winding channels, and lakes; this adds to the growing evidence that Mars once, long ago, had large volumes of water on its surface. Some photos taken by Mars Express spacecraft reveal ancient rivers and winding channel series of "pit chains" on the sides of volcano, which may possibly be places of life.

Over three and a half decades ago, NASA concluded that 1976 Viking rovers did not discover any evidence or traces of life on Mars. New analyses led (by a few scientists) to the conclusion that the NASA results from the Viking Robots, which landed in summer 1976, were wrong and the probe actually did find microbial life on Mars (Levin, 2011; Houtkooper and Schulze-Makuch, 2007; Bianciardi et al., 2012; cf. also to Navarro-González et al., 2010). NASA has launched the MSL (Mars Science Laboratory) mission that released the Curiosity Rover at the Martian Gale Crater. Curiosity landed on 6 August 2012 (after 9 months of space travel); it will search for water and organic matter that eluded two Viking probes in 1976. Moreover, an additional spacecraft for a robotic mission (ExoMars—by ESA with Russian space agency Roscosmos), scheduled for the end of this decade, is to drill ~2 m in the soil of Mars and analyze the scooped samples and those drilled from rocks in an attempt to detect building blocks of life. Perhaps life survives in the subsurface, in permafrost, in hydrothermal areas, or at the polar caps on Mars.

In addition, the unstable compound methane has been discovered on Mars which might support some bio-sources from methanogenic microbial activities. Methane-eating bacteria survived in Canada in extreme northern areas (such as in Lost Hammer Spring "LHS"—similar to areas present on Mars). The conditions in LHS are subzero temperature and high salty areas with no consumable oxygen (Miller and Whyte, 2012).

The search for life beyond Earth is in fact essentially the search for habitability on other worlds. In addition, biomarkers on extraterrestrial places should assist in finding traces of life beyond Earth. There have been some attempts (McKay et al., 1996) to discover traces of fossil nano-bacteria from a Martian meteorite that fell in Antarctica (ALH84001). However, several opponents rejected these observations (and conclusions) and claimed that the illustrations are just mineral artifacts (see descriptions by Kargel, 2004, p. 410; Reitner, 2004). Carbonates of the same microstructure as the host rock of the "ALH84001" have been discovered in rocks from alkaline Lake van which is the largest lake in east Turkey; it is a saline and soda lake (Kazmierczak and Kempe, 2003). That finding suggested, at least, that the hydrous environment on Mars was alkaline. Other chemical biomarkers were also observed in archaean rocks and on carbonaceous meteorites. It seems that traces of life in meteorites need further proof of its existence. Only after the return of samples from Mars to Earth (an MSR mission which might take place before the end of next decade) will we know for sure about life on other planets. Following the terraforming by Sagan (1961, 1967) and others, Friedmann and Ocampo-Friedmann (1995) pointed out the cyanobacterium *Chroococcidiopsis* for "Greening the Red Planet." For an older survey concerning life on Mars, see Brack and Pillinger (1998), while further information and recent photos of Mars have been presented by Kargel (2004).

4.1.2. Europa: The Ocean Moon of Jupiter

Among the extraterrestrial places within our solar system that are quite promising for being habitable sites are Mars, Enceladus (Saurian moon), and Jupiter's satellite Europa, which is one of the four Galilean moons of Jupiter. Europa is the smallest of the four Galilean moons of Jupiter. It is slightly smaller than The Earth's Moon and cracks and streaks crisscross its surface. This Jovian moon is the home of the solar system's largest subsurface ocean. Several moons of The nearby celestial bodies may carry subsurface oceans, and they may provide the greatest volume of living area in our solar system. Europa is considered one of the greatest potential places for microbial life habitability (Chyba and Phillips, 2001; Greenberg, 2010). Europa has under its 5–15 km ice sheet an internal salty ocean of ca. 100 km depth, under a hydrostatic pressure of 1,100–1,300 atm, which may contain living species. The geochemical conditions in this sub-icy ocean are assumed to be suitable for life, while the temperature in this ocean is estimated to be 4 °C (Chela-Flores, 2011) and under high hydrostatic pressure. Below the ice surface of Europa, the ocean is kept warm by tidal forces (Pappalardo et al., 1999) and perhaps by volcanic sources. For further information and photos of Europa, see Greenberg (2005) (cf. Pappalardo et al., 1999). A subsurface ocean predicted to be on Europa is located on Earth in Antarctica under the Vostok station; this might be the best analogue we have on Earth for Europa's ocean. It is located beneath 4 km of ice and contains salty liquid water, where microbes were observed deep in the icy layers. Microbial life likely should exist in Lake Vostok, but it is much more uncertain whether it might exist in Europa's subsurface ocean. The body of the Lake Vostok subsurface water is up to 1.2 km deep, and the temperature of the water is −3 °C, which does not freeze because of the heavily salted water and the icy pressure above its surface.

4.1.3. "JUICE" Mission to the Jovian Moons Next Decade

JUICE (Jupiter-ice-Explorer) is the next large ambitious space mission by ESA to visit the icy moons of Jupiter. The launch is planned to be realized in 2022, and after 8 years it will reach the target. Among the Jovian satellites to be covered are Callisto, Europa, and Ganymede (the largest moon in the solar system). The purpose of this mission is to investigate the possibility of habitability, to look for potential hosts for microbial life, and to measure the thickness of Europa's icy layer. All three moons are supposed to have a subsurface ocean, which means liquid water below their icy surface that might have environments conducive to simple biology. As we know, life requires a solvent (such as water), an energy source, and chemicals.

4.1.4. Penetrator with a Drill Designed to Enter into Europa's Ice

Lately there is a variety of instruments that aim to characterize the surficial properties of the Jovian satellite Europa. Proposals include landers or penetrators that carry a suite of instruments. Hard penetrator solutions have been proposed (Gowen et al., 2011), although so far this concept has to be demonstrated in the actual conditions that would offer the Europan environment (Korablev et al., 2011). More ambitious solutions have been envisaged in the Russian Laplace-Europa Lander Mission (Zelenyi et al., 2011). Although a total mass of over 1 ton was suggested, the more feasible penetrator still packaging a significant suite of miniaturized instruments would still be possible within a concept that is currently supported by ESA: the EJSM mission (Europa Jupiter System Mission) has to be reformulated due to the lack of funds. Fortunately, the new ESA project JUICE (JUpiter ICy moon Explorer) has left an attractive alternative (Dougherty et al., 2011), briefly, a mole-like thermal penetrator with a drill designed to bore through the icy surface of Europa in the future mission (to be launched in 2020). The thermal drill should be “the nose” of a penetrator, using heat to melt the ice and rotating drill blades to clear away rocky material and burrow itself into Europa’s ice shell. There are several models designed for the penetrator body shapes. Some of them are micro-penetrators—lightweight (5–15 kg) probes delivered to enter Europa’s body surface. Penetrators could provide information about mineralogy, geophysics, astrobiology, interior body structure, chemistry, mechanical and electrical properties, radiation environment, and magnetic, thermal surface/subsurface material, electrical, and thermal properties. The drilling action and penetration into the ice layer with the penetrator is vital since any landing probe that searches for biosignatures on Europa must go deeper than 2 m into the surface ice—due to heavy radiation and particle bombardment which could have erased any biological traces in the top layer. The plan is that the drilling into the icy crust layer searching for bio-samples should be from 1 m (which is sufficient to get beneath the radiation reworked surface) up to 10 m. The Europan upper ice thickness is between a few km and tens of km, while the internal ocean could be 100 km deep. On Europa’s ocean floor (at a depth of 150 km from the upper surface), it is assumed that there is a warm temperature environment, due to hot water-rock interaction. Such conditions may synthesize complex organic chemicals and produce energetic compounds that could support the emergence of life. The case of Europa’s drilling might be a model of other large icy satellites that have vast global oceans of liquid water deep underground.

4.1.5. Titan

Titan is the largest moon of Saturn. Its surface is very cold (−179 °C), and this satellite contains lakes and perhaps rivers of liquid methane and ethane. In this celestial body, there is no permanent surface body of liquid water or large quantities of CO_2. Both its liquid lakes and seas consist of hydrocarbons (methane and ethane). A region on Titan has been found to be similar to the Etosha Pan in northern Namibia, Africa. Both are ephemeral lakes, large, shallow depressions that sometimes fill with liquid (in Titan it is covered with hydrocarbons). Although there might be a possibility that the surface (if liquid hydrocarbons can take the role as solvents for life) or subsurface is habitable, we cannot currently know for certain. Titan does not have an atmosphere similar to Earth and is covered with hazy methane clouds which hide the surface. There is in its atmosphere CO_2 at the ppb level only. Its surface pressure is 1.5 bars. Environmental conditions on Titan and Earth were similar in many respects four billion years ago; thus, in various ways it is analogous to early Earth. Recently large tides have been observed by the Cassini probe on Saturn's moon Titan, which pointed out to a subsurface liquid ocean. This underground sea is mostly likely to be of water, located 100 km beneath Titan's icy surface and it swirling around below the surface (Kerr, 2012).

See comprehensive reviews of the Saturn system and especially Titan (and their references) by Raulin (2012), Raulin et al. (2004), and Simakov (2004).

4.1.6. Enceladus: The Satellite of Saturn (The King of the Rings)

Most of the information about Enceladus was obtained from flybys over this moon and not from rovers. There is a connection between internal liquid water reservoir and space. This moon has a great interest for astrobiology, due to the water-ice plumes on the surface; it has good chances for habitability. Enceladus has the tenth size of Titan (the largest satellite of Saturn); its temperature is −190 °C and its diameter is 500 km. The active ice volcanism comes from the internal hot rocks to the pressurized liquid water accumulation, to water ice, which comes out as plumes to the atmosphere. The clouds at the South Pole are composed of 65 % water vapor (from the aqueous plumes) while also CO_2, N_2, and CO were detected in the atmosphere (Shapiro and Schulze-Makuch, 2009).

4.1.7. Venus: Out of the Habitability Question

Focus is on Mars, Enceladus, and Europa in the search for habitable zones, but one might be surprised to know how much Venus has been explored—from initial telescope observations and the early flyby missions to the landers and orbiters. We know quite a lot about Venus, but the planet surely did not give up its secrets easily. We now know the physical conditions on this "Earth twin planet" which contains mainly CO_2 in its atmosphere. Venus is the hottest place in the solar system with a temperature of 750 °C, with a surface pressure of 90 bars. There is no possibility for finding any Cytherean life on the surface of the planet, but prior to the current data over Venus, there are some older proposals for Venusian microscopic life on its surface (Seckbach and Libby, 1970). Sagan (1961, 1967) and Morowitz and Sagan (1967) suggested terraforming Venus clouds by seeding the Venusian lower atmosphere with cyanobacteria in order to make this celestial land habitable. The rhodophytan *Cyanidium caldarium* (Seckbach, 1994) is able to tolerate severe condition close to Venus (such as CO_2, elevated temperature, acidic environment) and could be pointed out as a pioneer candidate for the Cytherean cloud settler. More recently Schulze-Makuch and Irwin (2002) and Schulze-Makuch et al. (2004) published their "hypothetic papers" about the possibilities for Venusian life. For more information on Venus and life possibilities, see Lomb (2012).

4.2. THE EXTREMOPHILES AS ANALOGUES FOR EXTRATERRESTRIAL BODIES: MARS AND EUROPA

Moons of the outer solar system carry subsurface oceans, and some of them have suggested being habitats of microbial life (Seckbach and Chela-Flores, 2012). However, is there any chance for finding life on the surface? In the past decades, some effort has been invested in locating terrestrial life forms on other planets. The recent book *Astrobiology* (Chela-Flores, 2011) discusses the new interdisciplinary field's concern with all of these extremophiles, as they may be models or analogues for survivors in similar extraterrestrial environments in space. A substantial amount of data about extraterrestrial bodies, mainly from the solar system, has come from a variety of sources (telescopes, surface rovers, flyby space crafts, and other means).

In the solar system and beyond, there might be habitable niches for organisms to exist in *life as we know it*. Until now, neither organic matter nor life has been detected on the Martian surface. It is extremely saline, has cold temperatures, and is desiccated and exposed to radiation. Mars possibly contains liquid water in spite of its harsh surface temperature. Speculation points out that the discovery of complex life in the Earth subsurface and deep aqueous environments (with organisms such as Pompeii worms, tardigrades, or mephisto nematodes) could have implications for the search for life on Mars or other places in our solar system. After all, it is agreed that bacterial spores are strong enough to withstand the journey to Mars (see McKay et al., 2012). As mentioned above, this planet was a warm-water world, good chances that in the past life could have thrived on the Red Planet. Spores from ancient microorganisms may be waiting dormant under the surface of this planet until a favorable change in their environment. We could compare it to *Bacillaceae* that were found sealed on Earth after 250 millions of years of dormancy and then revived (Vreeland et al., 2000).

4.3. BLOOD FALLS, ANTARCTICA AS A MODEL FOR EXTRATERRESTRIAL LIFE

An ancient ecosystem discovered beneath Antarctic glaciers at “Blood Falls” may also show how alien organisms might live in icy worlds. Blood Falls bacteria have thrived for millions of years beneath a rusty Antarctic glacier. The blood red color comes from an underground saltwater lake trapped by the encroaching glacier at least 1.5 million years ago. The water temperature is −5 °C (salt prevents it from freezing). The subarea is rich in iron salts—hence the source of the red hue (rust glacier). This is an ecosystem of bacteria trapped in a condition that could hardly be more inhospitable to life. The bacteria exist there without light penetrating the thick ice of the glacier to the lake lying 400 m beneath it. The microbes have lived there for millions of years, and the conclusion is that similar conditions may exist on planets and satellites where microorganisms are still waiting to be woken up.

4.4. CONCLUSION FOR POSSIBILITY OF EXTRATERRESTRIAL LIFE

Considering that a number of the polyextremophiles are adapted to multi-stress conditions, one could propose to perform "terraforming" of some celestial bodies such as Mars and others. This idea is not new, having been suggested in the literature (Sagan, 1961, 1973; Morowitz and Sagan, 1967; McKay, 1982), but at present we have more information about our neighboring planets and satellites. The cyanobacterium *Chroococcidiopsis* was pointed out for "Greening the Red Planet" (Friedmann and Ocampo-Friedmann, 1995). Also, *Cyanidium caldarium* members (Seckbach, 1994) could be good candidates for such Venusian clouds' terraforming. We have to remember that such extravagant planetary engineering of terraforming is far from the kind of experiment that we can control at the planetary scale.

If micro-life could stay dormant in our local planet for millions of years and then "wake up," why could not the same phenomenon take place in other extraterrestrial bodies? There is hope that in the future, we will find biosignatures of life further away from the solar system in habitable extraterrestrial locations.

5. General Summary and Conclusions

The term extremophiles refers to hardy organisms mainly prokaryotes and to a lesser extent eukaryotes, aerobic and anaerobic, microbes, and lower animals. While polyextremophiles are organisms that live under multiple forms of stress; some of their characteristics were discussed above. These microorganisms and some higher forms tolerate, live, or thrive in severe environments, such as in extreme ranges of temperatures, pH, hypersaline solutions, high pressure, oxygen scarcity, and a variety of radiations. They exist in dryness and desiccation for a long period and can be revived after millions of years in a dormant stage. The reader could find relevant information on extremophiles in Rothschild (2007), Stojanovi et al. (2008), and in the Springer series of *Cellular Origin, Life in Extreme Habitats and Astrobiology* (editor by Seckbach J., volumes 1–25 and further).

Due to their ability to live and survive in such very harsh and enigmatic conditions, these organisms were indicated as models for extraterrestrial life. Conditions on Mars, Europa, and Enceladus (and in the future perhaps Titan) may fit several of these extremophiles. The discovery of life on extraterrestrial bodies such as Mars, Europa, or elsewhere in the outer solar system would have a colossal effect and impact on science and society. The question is: Are we too hopeful in our hunt for extraterrestrial life, within the solar system, exoplanets, super Earth, and Goldilocks zones? The probability of life elsewhere in the universe is still a moot point—assuming life *does* exist somehow, somewhere besides Earth, would it really be all that alien? On the other hand, are they reachable for us? Again, if microorganisms may live in such severe environments on Earth, why could they not exist in similar niches on Mars or on other celestial places?

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