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# Antarctica and the Martian Analogy

**Contents**

## Introduction

Life is one of the most persistent phenomena on Earth. It seems that wherever conditions are even remotely favourable, there it is. Organisms can be found in the most arid of deserts: the frozen, inhospitable lands of Antarctica. Here species manage to carve out niches and survive, even flourish in their own unique way. The persistence of life on Earth is part of what drives us to search beyond our planet. Just how constant is this phenomenon we call life?

Investigations into the possibility of life on other worlds have no choice but to start on Earth. In order to model extra-terrestrial biological systems scientists must look to Earth-based systems for inspiration. Antarctica provides the exobiologist with a wealth of information. Here can be found some of the hardiest species living under the most extreme physical conditions on Earth. The cold, dry desert regions of Antarctica's Dry Valleys have been likened to the harsh Martian surface. Ice covered lakes are havens of biological activity. Could the same have been true on Mars as an atmospheric crisis led to increasingly hostile surface conditions? Investigations into the ecological niches occupied by Antarctic micro-organisms provide scientists with ideas of where to begin looking for evidence of life on Mars.

While Antarctica can provide useful analogies for Martian environments it is important to look at the differences and understand how they may limit the effectiveness of our modelling. Present day Mars varies from Antarctica; for example, in terms of atmosphere, UV flux and light and temperature regimes. Ancient Mars may have more closely resembled ancient Earth but present Earth conditions (temperate and polar) are very different once again. How far can the Antarctic analogies extend and what are their limits? How do these limitations affect how we ought to conduct investigations into life on Mars?

**The Origins of Life**

Finding out about the state of potential extra terrestrial biospheres is important for answering questions about the prevalence and origins of life in the universe. There is mounting evidence supporting the emergence of life on Earth as a process that began early in the planet's history[1] but there remain a number of unresolved issues.

The problem with investigations into the origin of life on earth is that the earliest organisms are likely to have been too delicate to be properly fossilised leaving no record of Earths earliest inhabitants[2]. Complicating matters is the dynamic nature of Earths crust. It is constantly being renewed by the effects of erosion, plate tectonics and volcanism. Most of the rocks on Earth are, geologically speaking, quite young. Having said that, there are a few genuinely ancient examples of crust to be found. The oldest rocks containing morphological fossils are around 3.3 – 3.5 billion years old[3]. Found in South Africa and Australia, they contain structures identified as microfossils and stromatolites[4]. Off the coast of Greenland can be found an outcrop that is 3.8 billion years old: within this rock are, not fossils, but mineral grains - the carbon isotope ratios of which suggest they may be the ancient, highly decayed by products of living systems[5].

It seems likely that life on Earth evolved early in its history and there is a growing belief that life did not struggle to start. Within 300 million years of the end of heavy bombardment of the Earth's surface a diversity of life existed flourishing in stromatolite forming colonies in different parts of the world.

At an early stage, it is reasonable to think that Earth and Mars were likely quite similar. Silicate crusts, molten iron cores and hydrogen atmospheres as high UV exposure triggered the formation of many organic and inorganic

[1] Bizony, (1998). 'The Exploartion of Mars: Searching for the Cosmic Origins of Life'
[2] ibid.
[3] Westall et al (2000)
[4] Carr, (1996). 'Water on Mars'.
[5] Moorbath, (2005)

molecules. The ancient atmosphere that formed did not resemble present-day atmospheric conditions. Formed largely from volcanic activity, the first atmosphere was likely composed of methane, ammonia and water vapour[6]. UV light operated to liberate oxygen from water, which attacked ammonia and liberated nitrogen, or methane and formed carbon dioxide[7]. Hydrogen, too light to be contained by Earth's gravitational field, escaped into space. The atmosphere transmuted into $CO_2$ and $N_2$ with water vapour clouds[8]. Within these three molecules are found the four elements that together make up 96% of the biomass on Earth[9]. The ingredients of life.

At the same time as these processes were occurring on Earth, similar processes were likely occurring on Mars. Four billion years later Mars' atmosphere is mostly $CO_2$ with 2.7% residual $N_2$[10]. Water content in the atmosphere is low but water vapour clouds can be seen and water ice is found locked up in the North Pole[11]. Earth had the ingredients of life and so too did Mars.

Exactly how life emerged on Earth is a matter of great speculation. Hydrothermal vents beneath the oceans are considered likely locations, with their constant energy input and rich nutrient supply. The most primitive surviving examples of Earthly life are photosynthetic bacteria such as the green sulfur bacteria, purple photosynthetic bacteria and cyanobacteria[12]. The earliest organisms would have utilised anaerobic photosynthetic processes, employing molecules such as $H_2S$ to reduce $CO_2$ and make organic compounds without the production of molecular oxygen[13]. However, the fossil evidence of the ancient stromatolites suggests that by 3.5 Million years ago photosynthetic organisms that produced $O_2$ had emerged. Before too long the oceans would have been full of these blue/green algae. Protective pigments

[6] Bizony (1998). 'The Exploartion of Mars: Searching for the Cosmic Origins of Life'
[7] ibid.
[8] ibid.
[9] ibid.
[10] Carr (1981). 'The Surface of Mars'.
[11] ibid.
[12] Falkowski and Raven, (1997). 'Aquatic Photosynthesis'
[13] ibid.

shielded them from UV damage and the algae thrived, to the extent that their waste production fundamentally altered the atmosphere of Earth and life had to adapt, find new strategies to cope and even utilise the toxic oxygen atmosphere. With the acquisition of oxygen came another molecule, $O_3$, ozone, and Earth had its first truly significant protection from the damaging effects of solar radiation.

On Mars it was a different story. As Earth was acquiring its oxygen/nitrogen atmosphere and settling into a period of relative stability, Mars was beginning to cool. Further from the Sun, it receives only 43% of the solar energy of Earth[14]. In addition its core was cooling much faster than Earth's[15], reducing the effects of geothermal heating. Water began to freeze and $CO_2$ precipitate out at the poles, reducing the atmosphere and adding to the cooling effect. In addition, the smaller mass of Mars means that both $O_2$ and $N_2$ could escape the planet's gravity well[16]. This occurred over a long period but the Martian atmosphere continued to thin and the planet to cool.

Given their similar early histories it is quite possible that similar organic processes as occurred on Earth also occurred on Mars, but as the planets' fates diverged so too did the course of life. As life on Earth adapted to a thriving, temperate planet any life on Mars must have been adapting to a dying world. Retreating into habitats where temperatures allowed liquid water to exist and life could be protected from an increasing UV flux. Some may have gone into states of dormancy and been frozen in ice caps or permafrost. Given the current conditions on Mars, it is unlikely that anything on the surface could survive, but life is persistent and if it can find a way, it will.

[14] Mancinelli and Banin, (1995).
[15] Bizony, (1998). 'The Exploartion of Mars: Searching for the Cosmic Origins of Life'
[16] Carr (1981). 'The Surface of Mars'

## Looking for life in Antarctica and on Mars - *The importance of water*

*Someone once said, when trying to understand the motivations of men always ask "where's the money?" When trying to work out where life exists one must always ask "where's the water?"*

Water, by virtue of its unusual physical and chemical properties, is an essential component for all life on Earth and in all probability off Earth as well. The exceptional ability of water to form hydrogen bonds has given water a much higher boiling point, melting point, heat of vaporisation and surface tension then would be expected of a substance of such a low molecular weight that is neither metallic nor ionic[17]. Its polarity and importance as both a hydrogen donor and acceptor make it an important solvent in living systems. Water is also required for the proper formation of cellular membranes. Most cells on Earth are 70 – 90% water and generally, at 65% or less, normal metabolic activity cannot occur.[18]

Understanding the importance of liquid water to Earth based biological systems brings us to why Antarctica is considered an important model for Mars. As it exists now, water on Mars is scarce and liquid water appears to be non-existent. In Antarctica, the vast majority of the water is locked up in the ice sheet and is unavailable to biological systems. What life does exist still has a biological reliance on water for metabolic processes but has adapted to the extreme scarcity.

Always keeping in mind the needs of life for liquid water helps understanding of why certain niches exist and how they operate to maintain living systems in extreme environments such as Antarctica and indeed, potentially, Mars as well.

[17] Garret and Grisham, (1999). 'Biochemistry'
[18] ibid.

*Water on Mars*

Given the importance of water, its past or present existence on Mars is really a necessity if we are to even consider the possibility of life. What is more, the emergence of life is unlikely in an extreme habitat where water is scarce. Organisms may adapt to such a locality, but the earliest micro-organisms would most likely have developed only in an abundance of water[19]. On Earth life is believed to have first emerged in the oceans[20]. What evidence is there for significant, stable bodies of water on ancient Mars?

The only place on Mars where a significant amount of water has been clearly identified on the surface is at the North Pole where a permanent water ice cap is exposed when the $CO_2$ cap sublimates during the Northern summer[21].

Geological features suggesting the past or present existence of water include; outflow channels, terrain softening at high latitudes, stratified polar deposits, polygonal fractured ground, mottled plains, strandlines and layered sediments[22]. Outflow channels are the most unmistakable features suggesting the presence of large amounts of water on Mars' surface. (See Figure 1). The most widely accepted explanation for their existence is the occurrence of huge floods[23]. Those originating from canyons are thought to be due to the catastrophic drainage of large lakes, others due to massive eruptions of

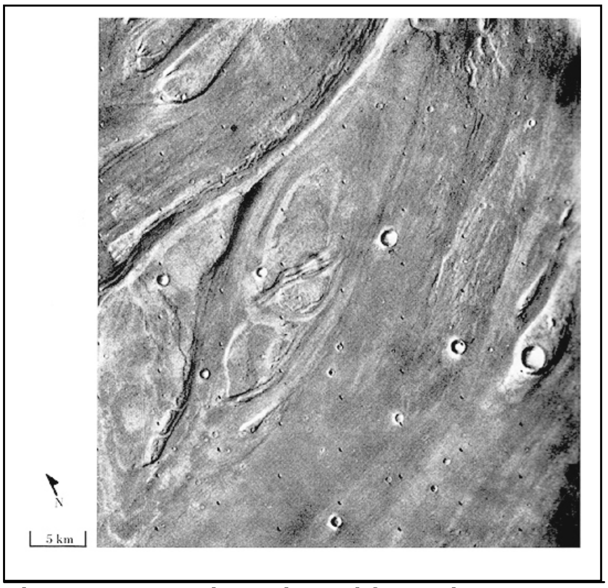


**Figure 1 – Tear drop shaped forms in an outflow channel are very characteristic of water based erosion.**

[19] Fry, (2000). 'The Emergence of Life on Earth'
[20] ibid.
[21] Carr (1981). 'The Surface of Mars'
[22] ibid.
[23] Carr, (1996). 'Water on Mars'.

ground water[24]. Conservative estimates of the volume of water required to carve these geological features is about 60m distributed globally[25]. This would of course represent only part of the planet's total water inventory.

Terrain softening is when features such as crater rims become less well defined. (See Figure 2). This softening is seen at high latitudes only and is thought to be due to creep of near surface materials as a result of ground ice[26]. Another indication of the presence of possible ground ice is the stratified polar deposits, which appear to contain permafrost. Given current surface conditions, ground ice would be unstable at lower latitudes, but above 40° would be stable at depths of only a few metres[27]. The existence of significant quantities of frozen ground water on present day Mars would account for a proportion of the planet's earlier water inventory.

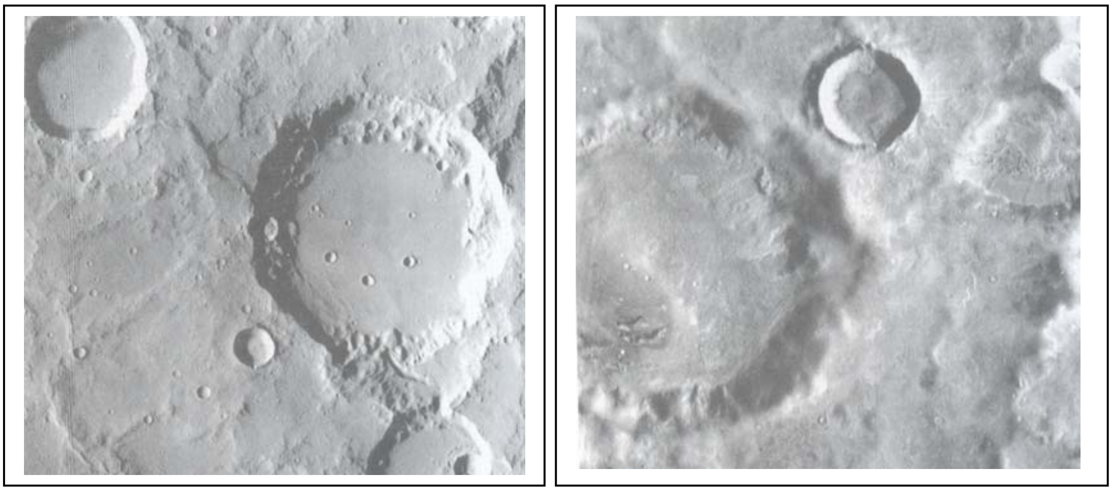

**Figure 2 - The first picture (Viking Orbiter Frame 443S10) is of a low latitude crater with the normal sharp definition. The second picture (Viking Orbiter Frame 575B59) demonstrates contrasting terrain softening at higher latitudes.**

Polygonal fractured ground occurs in the northern plains and seems to be associated with the outflow channels[28]. Current thought is that the patterns are the result of multidirectional contraction and compaction of sediments that were deposited out of the channels[29]. Similarly, mottled plains are generally

[24] ibid.
[25] Carr, (1996). 'Water on Mars'.
[26] ibid.
[27] ibid.
[28] ibid.
[29] ibid.

located near channel endings. Their distinct patterns of erosion are suggestive of thermokarsts[30] (backwearing and removal of ground ice by ablation result in the mottled appearance of thermokarsts). These features may have been ice rich deposits formed from frozen lakes[31].

Strandlines are linear features suggestive of former shorelines[32]. Baker et al propose the possibility of the periodic formation of global oceans of which such strandlines would represent the ocean shore[33].

Thick sequences (the largest is 8km) of layered sediments can be seen within several of the massive canyons[34]. Nedell et al considered a number of possible sources for these features and concluded that a substantial, long lived lake provides the best explanation for the particulars, such as the horizontality, lateral continuation and thickness, of the deposits[35]. Evidence of fluvial features at the east end of Valles Marineris supports this position[36].

That there has been water on Mars is of little doubt, but exactly how much, when, where and for how long are still matters of great debate. High rates of valley formation and erosion at the end of heavy bombardment are widely attributed to warm, wet climatic conditions at this time[37]. The planet likely began cooling soon after but for a time conditions appear to have been suitable for the emergence of life. The possibility of long lived lakes is very promising. As the planet cooled, these may have frozen over but remained liquid at depth, providing an important habitat as surface conditions became too hostile to support life.

[30] Carr, (1996). ‘Water on Mars’.
[31] ibid.
[32] ibid.
[33] Baker et al, (1991).
[34] Carr, (1996). ‘Water on Mars’.
[35] Nedell et al, (1987).
[36] Carr, (1996). ‘Water on Mars’.
[37] ibid.

***Water in Antarctica***

In Antarctica the majority of the water is frozen in the ice sheet. Precipitation is exclusively in the form of snow and the low temperature and dry air means that, in most locations, sublimation tends to occur over melting. Liquid water is extremely scarce; however, there are a number of places it can be found -  ice capped and hyper-saline lakes in the Dry Valleys, sub-glacial lakes deep below the Antarctic ice sheet and, on a smaller scale, microclimates such as within porous rocks or on the surface of glaciers strewn with dark dirt. And where liquid water exists, even in only a transitory way, life manages to survive.

## The Antarctic Model - Antarctic Terrestrial Microbial Communities

### *The Dry Valleys*

The Dry Valleys of South Victoria Land represent the most extreme cold desert environment to be found on Earth[38] and are widely considered to be the closest terrestrial analogue to Mars. The valleys are part of only 2% of the Antarctic continent free of permanent ice and snow cover[39]. There, the flow of glaciers out of the East Antarctic ice sheet is cut off by the Trans-Antarctic Mountains. The annual depletion of the ozone layer over Antarctica results in a twofold increase in UV-B radiation in the spring. The mean annual temperature in the region is -20°C to -25°C and even during the summer, when the sun never sets, the air temperature rarely rises above 0°C[40]. The cool temperatures mean the air is dry and precipitation consequently low. However, within this environment microbial communities still manage to exist in a range of niches. Lakes represent the greatest source of continuously liquid water, niches just within the surface of rocks buffer organisms against the harsh environment, and even the dry desert pavement contains living micro-organisms.

### *Dry Desert Pavement*

In contrast to the generally cold climate, the ground surface can reach temperatures well above 0°C as solar heating acts on the darker coloured rocks[41]. Diurnal freeze/thaw cycles are common in the summer months as the Sun moves around the sky and is blocked by the mountains around the valleys. Precipitation is rare and when it does snow, the lack of humidity means that, typically, the snow sublimes without any visible wetting of the ground[42]. The soil in the Dry Valleys is saline and sometimes alkaline[43]. Beneath the surface, at depths from a few centimetres to over a metre, can be

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[38] Vishniac, (1993).
[39] ibid.
[40] Horowitz, et al, (1972).
[41] ibid.
[42] ibid.
[43] ibid

found hard permafrost[44]. This environment is generally considered to be the most similar on earth to the Martian environment. Much of the Martian surface is dominated by vast plains of cold desert pavement. It is theorised but unconfirmed that at higher latitudes beneath the Martian dust may exist permafrost such as in Antarctica[45].

Organisms within the Dry Valleys are almost exclusively microbial. Away from lake shores and glacial melt pools and streams, the number and diversity of organisms measured in the soil diminishes significantly[46]. Samples taken from the driest parts of the valleys appear to contain no detectable micro-organisms[47], suggesting water is the limiting factor for these microbes.

In the most hostile environments that microbes are still detectable only heterotrophs are found[48] - no photosynthetic bacteria or algae; that is, no primary producers, suggesting incomplete soil ecology[49]. Typical organisms are aerobic, mesophilic, heterotrophic, non-spore forming[50] rods or cocci[51]. Usually pigmented near the surface (most likely for UV protection), they become less so further down. Halotolerance is surprisingly low, especially considering the salinity of the environment; however, this appears to be a function of temperature[52]. The halophiles do not appear to operate well in the cold.

There is some question as to whether or not the bacteria detected in the more inhospitable regions can be considered indigenous to the area. The lack or primary production and specificity to the environment (mesophiles over psycrophiles, not much halotolerance) suggest that species have not evolved within the environment to cope specifically with the conditions. Measurements

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[44] Carr, (1996). 'Water on Mars'.
[45] ibid.
[46] ibid.
[47] Cameron, (1969). JPL *Technical Report 32-1378*
[48] Horowitz, et al, (1972).
[49] Ibid.
[50] Spore formers are rare. The suggestion is that rapid changes in microclimatic conditions, especially temperature changes crossing 0°C and the subsequent moisture limitations do not allow enough time for spore formation (Ant MB Ice sheet section).
[51] Horowitz, et al, (1972).
[52] ibid.

of biological activity of Dry Valley micro-organisms based on the rate of $^{14}CO_2$ production per hour per organism was higher then in samples taken from temperate regions (specifically the JPL grounds)[53]. Researchers on this project came to the conclusion that the additional activity was most likely due to the presence of dead but enzymatically active cells. The high proportion of dead or dying cells suggests a lack of adaptation to the environment. In addition, Anderson air sampling from a location in the Taylor Valley showed bacteria populations essentially the same as populations in the soil at the same location[54], thus supporting the possibility of wind blown populations rather than indigenous ones.

Molecular work on dry valley soils suggests diversity is greater then it first appears. Much of the earlier research that included ‘sterile’ soils could in actual fact only say about those soils that they contained no organisms capable of growth on nutrient agar[55]. Only a few samples from the Asgard Range are confirmed sterile and this has been attributed to toxic levels of boron in the soil[56]. Populations are more extensive then first thought; however, by any method, microbial populations in the most arid parts of the Antarctic desert appear to be small[57]. While viable micro-organisms can be thought present in all, non-toxic, dry valley soils, viability is not the same as being a member of a microbial community.

The issue of endemism is still a matter of debate; however, there is mounting evidence that organisms are able to survive in even the most hostile environments Antarctica has to offer. More than likely such organisms spend the majority of their time in a state of hibernation with the possibility of a few cell divisions if the ground gets warm after a snowfall. The essential limiting factor appears to be the availability of water. It seems that the majority of dry valley soils, once wetted, are capable of supporting microbial growth[58]; however, for many of these soils, sufficient water for such processes is rare.

[53] Cameron, (1969). JPL *Technical Report 32-1378*
[54] Cameron and Merek, (1971). JPL. *Technical Report 32-1522*
[55] Vishniac, (1993).
[56] ibid.
[57] ibid.
[58] Cameron and Merek, (1971). JPL. *Technical Report 32-1522*

### *Cryptoendolithic communities*

A particularly interesting aspect of biology within the dry valleys is the role of rocks as microbial niches. Cryptoendolithic communities are literally microbial communities hidden inside rocks. The harshness of the desert environment means that, for the most part, the surfaces of rocks are abiotic[59]. The same cannot be said for just below the surface. In response to the aridity of the region a number of species have withdrawn into niches inside certain rocks where nanoclimatic conditions are more habitable. Conditions vary on the millimetre scale in moving from above to below the surface, and it is on these kinds of scales that micro-organisms exist.

Organisms in these communities live in the interstitial spaces of porous rocks a couple of millimetres below the rock crust. These communities depend on photosynthesis for primary energy production so the favoured rocks contain high quartz content through which light may be transmitted to a depth of a few millimetres. This dependence on photosynthesis limits the depth of colonisation, especially as, on these scales, a steep light gradient exists.

The porous sandstone rocks that are typically colonised have a relatively large grain size (0.2 – 0.5mm) and a quartz framework[60]. Within the grain matrix are $Fe^{3+}$-containing oxy-hydroxides which tend to give the rocks a yellowy or brown colour known as an iron stain[61]. Darker rocks with albedoes >0.5 are preferentially colonised, probably due to better light absorption and therefore, warmth[62]. The surface of these rocks is covered by about 1mm of silified crust which likely stabilises the surface and reduces wind erosion[63].

The environment within in the rock has several advantages. Solar heating means that summer temperatures can be significantly higher than ambient temperature, by as much as 20°C for a north facing surface and 8°C for a

[59] Nienow and Friedmann, (1993).
[60] ibid.
[61] ibid.
[62] ibid.
[63] ibid.

south facing surface[64], allowing melting of accumulated snow (the only water source for these communities[65]) and thus liquid water. A period without direct sunlight, such as shading or cloud cover, results in significant radiative cooling of the rock surface and temperatures may change extremely and rapidly[66]. Or in cool, windy, but still sunny conditions 0°C may be crossed several times in a short space of time[67]. Within the rock these changes are buffered. They occur slower and thus allow organisms time to adjust. Another advantage of the endolithic habitat is the absorptive power of these rocks along with significant retention of water in the spaces of the porous sandstone days or weeks after a snowfall[68]. Precipitation may be rare but these communities are able to make the most of what is available. In addition, oxalic acid production by endolithic organisms increases the acquisition of many nutrients directly from the rocks[69]. The communities do not appear to be nutrient limited.

Five types of microbial communities have been identified as inhabiting cryptoendolithic environments. Two are dominated by eukaryotic algae and fungi and three by cyanobacteria[70]. The most conspicuous feature of these endolithic communities is very distinctive vertical zonation corresponding to a steep light curve[71]. Most communities have two major zones; an upper, closest to the rock surface and subject to greater light intensity and a lower, experiencing significantly reduced light flux[72]. The upper zones are often more darkly pigmented, probably in direct response to the greater light intensity[73]. Heterotrophic bacteria are also associated with all community types in no defined zone[74].

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[64] Nienow et al (1988a)
[65] Friedman, (1978).
[66]Nienow and Friedmann, (1993).
[67] McKay and Friedman, (1985)..
[68] Nienow and Friedmann, (1993).
[69] ibid.
[70] ibid.
[71] Nienow et al (1988b)
[72] ibid.
[73] ibid.
[74] Nienow and Friedmann, (1993).

There are a variety of nanohabitats inhabited by a variety of communities. Humidity appears to be the principle controller of community distributions[75], with secondary factors such as pH and rock chemistry also dependent on the humidity of the rock. The *Hormathonema-Gloeocapsa* community have only been identified in the Battleship Promontory in the white sandstone rocks that are frequently wetted by melt water off Mt Gran - these communities experience pH 7.3-8.2[76]. The *Chroococcidiopsis* communities appear quite rare and are found on the valley floor. Here conditions are often drier. This community seems to prefer relatively cold and dry conditions and are not found at elevation[77]. The Red *Gloeocapsa* community is better adapted to the lower pH (3.7 -5.5) that often comes with drier conditions[78]. It is clear that different cyanobacteria are capable of living in a range of endolithic habitats. They appear to be very well adapted organisms.

On a macro scale, cryptoendolithic colonisation is often apparent as distinctive weathering patterns on rocks[79]. This manifests as mottled colours due to terracing on the surface of colonised rocks. The terracing is a result of exfoliation of the crust. Microbial activity such as acid production[80] (oxalic acid, amino acids), reduces the cohesion of the grains in upper layers and as a result these upper layers are constantly flaking off[81]. As this occurs the community moves down, deeper into the rock. This process results in the gradual destruction of the colonised rock and often results in eye-catching rock formations such as the Battleship Promontory in the Convoy Range[82]. (See Figure 3)

The most studied community is the lichen dominated with which weathering is quite evident. Of the cyanobacteria dominated communities the *Hormathonema-Gloeocapsa* community produces a distinctive pattern of

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75 Nienow and Friedmann, (1993).
76 ibid.
77 ibid.
78 ibid.
79 ibid.
80 Friedman and weed, (1987).
81 Nienow and Friedmann, (1993).
82 ibid.

blackish lines over the white sandstone rocks that they inhabit[83]. The other cyanobacterial communities are less well described but the processes associated with the biogenic weathering would likely occur in most, if not all, cryptoendolithic communities. The weathering patterns are a key method of identifying locations of such communities and are likely to be a distinct fingerprint of the existence of such communities in the past. This would be of great importance when looking for evidence of extant or extinct life on Mars. If such cryptoendolithic communities existed on Mars, providing sheltered niches for species, then the biogenic weathering patterns would likely have left their mark on the landscape. Given the age of much of the Martian landscape, it is possible that outcrops marked by the passage of these life forms could be identified, even 3.5 billion years later.

**Figure 3 – Bizarre rock formations at the Battleship Promontory**

[83]Nienow and Friedmann, (1993).

### *Ice Covered Lakes*

Antarctic Dry Valley lakes have been suggested as analogues of paleolakes on Mars. Such lakes would have provided shelter for organisms as Mars began its evolution towards the cold, dry environment seen today.

Such Martian lakes would have likely contained liquid water beneath frozen ice caps[84], at least to begin with. If heated from below by geothermal activity (as is believed to be the case with Lake Vanda[85]) and fed by subterranean sources to prevent drying out, it stands to reason that such lakes could have existed for a significant period of time as habitats, even as the surface became increasingly inhospitable. In addition, biological activity beneath Antarctic ice capped lakes serves to concentrate atmospheric gases[86]. This would be particularly important to Martian species as the planet's atmosphere thinned. The presence of ice caps on Martian lakes would serve to isolate such systems and shield them from the huge variations in temperature and the increasing UV flux.

The environment of perennially ice covered lakes in Antarctic dry valleys is, by and large, controlled by the ice cap[87]. The ice cap serves to mostly isolate the system. It eliminates wind generated currents resulting in meromictic waters, with a surface zone of freely circulating water called the mixolimnion separated by a steep density gradient from the monilimnion, the non mixing zone[88]. The effect is chemical and thermal stratification of the lake waters[89]. It also limits gas exchange with the atmosphere, reduces the amount of light penetration into the water column and limits deposition of sediments[90].
Within the dry valley lakes can be found a variety of chemical compositions., Water directly below the ice cap of Lake Vanda, in the Wright Valley, is cold

[84] Wharton, et al, (1989).
[85] Laws, R.M., (ed), (1984). 'Antarctic Ecology: Volume One'
[86] Wharton, et al, (1989).
[87] ibid.
[88] Laws, R.M., (ed), (1984). 'Antarctic Ecology: Volume One'
[89] Wharton, et al, (1989).
[90] ibid

(0°C), very fresh (<0.2gl$^{-1}$ chloride ions) and super saturated with oxygen[91]. Bottom waters have been measured at 76gl$^{-1}$ chlorides, are anoxic and warm (temperature at the bottom has been measured at 25°C[92]).

Lakes Bonney, Fryxal and Hoare in the Taylor Valley are similarly ice capped and demonstrate chemical and thermal stratification. Maximum temperatures are not as high and occur at shallower depths[93]. This is thought to be because geothermal heating plays a role in heating Lake Vanda but heating in the other lakes is exclusively solar[94]. The ionic compositions vary from lake to lake; for example, the chlorides in Lakes Bonney and Fryxal are mostly NaCl and $MgCl_2$[95], while Vanda is mostly $CaCl_2$[96]. Sulfur compounds are found in the lower levels of Lake Vanda[97] and Lake Fryxal has a quite high $HCO_3$ content compared to other lakes[98].

An interesting variation of the ice capped lakes is Lake Vida. Thought for many years to be shallow (10m) and frozen to the lake bed[99], more recent research has revealed that it actually consists of 19m of ice below which is highly saline liquid water which remains unfrozen to temperatures as low as -10°C[100]. In this lake light levels are non-existent at the water ice interface and temperatures are very cold[101]. Vida is an ice sealed lake[102], distinguishing it from other dry valley ice capped lakes. It receives no glacial input during the summer. Environments such as Vida could represent the last trace of Martian aquatic habitats.

Ablation is the primary water output for these lakes[103]. As water freezes to the bottom of the ice cap, ice is ablating into the dry atmosphere. Without any

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91 Wharton, et al, (1989).
92 Laws, R.M., (ed), (1984). 'Antarctic Ecology: Volume One'
93 Ibid.
94 Ibid.
95 ibid.
96 ibid.
97 ibid.
98 ibid.
99 Doran et al, (2003).
100 ibid.
101 ibid.
102 ibid.
103 McKay et al (1985)

input, such as from glacial melt or subterranean waters (perhaps from melting permafrost) these lakes continuously lose water to the atmosphere. Dry Valley lakes are believed to have gone through alternating dry periods, where water may have dried up completely or left only ponds of highly concentrated ionic solutes, and pluvial periods, where salts re-dissolved, fresh water flowed over the top of the dense brine and lake waters became meromictic[104].

The existence of a year round ice/water interface (that is, the lake is never frozen solid or completely melted) is largely due to very cold mean temperatures ensuring the stability of the ice cap and comparatively warm summer maximums so as that a certain amount of seasonal ice cap melt occurs and glacial melt waters can deliver latent heat to the water body so as it does not freeze entirely[105]. Mars also experiences cold averages and relatively warm maximums supporting the possibility that such lakes could have existed. Even if, as the planet cooled, the ice cap balance swayed towards freezing, Lake Vida, with its 19m ice cap above highly saline bottom waters could probably be representative of the final stage of ice covered lakes on Mars before they froze completely and eventually ablated.

Biological implications of the physical environment of ice covered lakes include restriction of primary production due to reduced solar radiation. With as little as 1% of incident light penetrating into the water column[106], phytoplankton is naturally going to be affected. Ironically, photosynthetic organisms are found fairly deep at the oxic/anoxic boundary where nutrient levels are high even if light levels are low[107], suggesting a high efficiency of photosynthesis among such lake species. The reduction in light limits the density and the lack of currents that would normally keep free floating plankton suspended means that water column phytoplankton is restricted to swimming forms.

[104] Laws, R.M., (ed), (1984). ‘Antarctic Ecology: Volume One’
[105] McKay et al (1985)
[106] Wharton, et al, (1989).
[107] Laws, R.M., (ed), (1984). ‘Antarctic Ecology: Volume One’

$N_2/O_2$ ratios measured at 12 metres and just below the ice within Lake Hoare suggest that nearly half the $O_2$ gas balance within the lake can be attributed to biological processes[108]. The ice cap limits exchange with the atmosphere so gasses build up in the water. The chemical and thermal stratification means that oxygen is distributed unevenly up and down the water column and organisms less able to cope with oxygen toxicity exist in lower levels.

Benthic microbial mats composed primarily of cyanobacteria with eukaryotic algae and heterotrophic bacteria are abundant within these lakes. Extending from the shoreline to depths of 20cm into the monilimnion, they can be as thick as 5cm in places[109]. These mats precipitate calcite, iron and sulphur and trap and bind sediments[110]. The result is alternating layers of organic and inorganic material. The formation of these laminated mats into stromatolites (easily recognisable banded patterns formed by the lithification of the alternating organic and inorganic material of laminated microbial mats,[111]) has important implications for Martian exploration. Ancient stromatolites are an important part of the fossil record[112]. That these structures form under these conditions means that if life indeed existed on Mars in similar habitats, then perhaps similar structures could have formed and been similarly preserved.

[108] Wharton, et al, (1989).
[109] Laws, R.M., (ed), (1984). 'Antarctic Ecology: Volume One'
[110] HB or Ant MB lake section
[111] Carr, (1996). 'Water on Mars'.
[112] Fry, (2000). 'The Emergence of Life on Earth'

***Micro-organisms in the Ice Sheet***

Studies of inoculum from the centre of ice cores at Vostok station provide the greatest wealth of knowledge regarding the survivability of micro-organisms in ancient ice. Locations such as the East Antarctic ice sheet are natural laboratories for the study of long term, low temperature anabiosis. Micro-organisms are carried on air currents from locations on the continent and from lower latitudes. They can become embedded in the ice and preserved. The small water ice cap present at Mars' North Pole could conceivably contain preserved microbial cells.

Because the numbers of organisms found in studies of ancient ice and permafrost are very low, relatively large samples are taken, between 500 and 4000ml per core[113]. Potato broth with yeast extract added is used to reactivate anabiotic organisms, and microscopic methods are employed to see what non-viable organisms are present[114]. Reliability tested methods[115] for obtaining aseptic samples have been used for all the biological Vostok cores.

Microbiological investigations on the Vostok ice core began in the 1974/75 season. By 1979/80 cores to a depth of 320m, representing ice as old as 13,000 years, had been examined and a range of viable organisms found[116].
From 114m downward the number of viable organisms decreased with depth. Above 100m 20% of samples contained viable micro-organisms[117]. At 200m this decreased to 14% and at 300m to 10%[118]. At the lower depths, between 1500 and 2400m (samples up to 200,000 years old), less than 3% of samples had viable cells[119]. However, scanning electron microscopy on filters through which samples had been passed showed microbial cells even in cores containing no viable organisms[120]. Viability is not necessary for prolonged

[113] Abyzov, S.S., (1993).
[114] ibid.
[115] ibid.
[116] ibid.
[117] ibid.
[118] ibid.
[119] ibid.
[120] ibid.

preservation of cellular structures. The Martian ice cap is much older than the Antarctic ice even at the greatest depths. If organisms are unable to remain viable for these sorts of time periods dead but morphologically preserved organisms would be just as exciting a find.

In relatively young layers of the ice sheet, a variety of viable micro-organisms were found, including yeasts, mycelial fungi, and a prevalence of both spore forming and non-spore forming bacteria[121]. The proportion of non-spore forming bacteria dropped off rapidly over the top 300m and the proportion of spore forming bacteria increased significantly[122]. At 300m, representing and age of 11,600 years, 75% of viable organisms recovered were spore forming bacteria[123]. The proportional amounts of other types of micro-organisms drops off from this depth. At the greatest depths, 200,000 years and older, the only viable organisms found were spore forming bacteria[124].

In the younger layers the types of organisms found included both obligate psychrophiles and mesophiles[125]. Psychrophilic organisms are quite likely to have been indigenous to Antarctica, while the presence of the mesophiles, deemed likely to originate from temperate regions[126], emphasises the role that air currents play in transporting micro-organisms into the region.

At depths below 2,400m only a few samples contained viable micro-organisms and they were exclusively spore forming bacteria[127]. The ability of bacterial spores to become vegetative after long periods of time is well documented. Periods of several hundred thousand to several million years are suggested, especially if preserved at low temperatures away from any harmful environmental factors[128]. It is unsurprising then that it is these organisms that are most prevalent in the Antarctic ice sheet, and it is also such organisms

[121] Abyzov, S.S., (1993).
[122] ibid.
[123] ibid.
[124] ibid.
[125] ibid.
[126] ibid.
[127] ibid.
[128] ibid.

that would have the greatest chance of remaining preserved in the Martian water ice cap. The viable bacteria are predominantly mesophilic and the growth temperature range is broad, from 4°C to 50°C[129]. Strains show lower enzymatic activity than the same species isolated from temperate regions, most likely due to the prolonged period of inactivity, but there does appear to be a gradual recovery of activity[130]. Spore formers are uncommon over much of the continent so the organisms found in the deepest levels of the ice sheet are likely to have been carried on the wind from warmer climates.

The distribution of different types of viable micro-organisms shows a very clear link between depth and resistance to unfavourable conditions. The spore formers being the most resistant organisms are the most capable of surviving prolonged periods of anabiosis and possibly reviving when conditions change. If anything survived in the Martian ice cap for the last 3.5 billion years it would have to be spore forming or something similar.

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[129] Abyzov, S.S., (1993).
[130] ibid.

### ***Sub-glacial Lakes***

More than 70 lakes have been identified beneath the thick Antarctic ice sheet using ice-penetrating radar[131]. The largest of these, Lake Vostok, identified in 1996[132], is 250km long, 40km wide and is 400m deep[133].

Russian scientists have been drilling into the ice sheet above Lake Vostok for a number of seasons, looking at ice cores. In 1998 drilling stopped at 130m above the lake's surface[134]. At this location, the ice being accessed is accretion ice; that is, frozen lake water. Samples of this ice have been shown to contain organisms which suggest the lake may support a small, slow-growing, microbial ecology[135]. Accessing such organisms would be a most interesting exercise. These subglacial lakes are buried under several kilometres of ice. They are under enormous pressure and have been isolated from the sun and the atmosphere for the last 15-30 million years[136].

The lakes are believed to remain liquid due to basal melting[137]. Their presence is therefore largely a matter of topography. Water freezes to the bottom of the ice sheet in one part of the lake then as the ice sheet moves it encounters sloping bedrock and frictional heat produced results in melting.

The existence of these lakes in Antarctica has sparked interest in the possibility of similar subglacial lakes existing under the northern water ice cap on Mars. If there are indeed organisms in Lake Vostok then perhaps Martian subglacial lakes could be capable of supporting extant life. Completely isolated from the Martian surface, anything in these lakes would not have to face the same extremes that appear to preclude extant life over the majority of Mars. If such lakes do indeed exist, they would appear to be only location on the planet harbouring liquid water and that is a very interesting prospect.

[131] Simmons et al, (1993)
[132] ibid.
[133] http://www.resa.net/nasa/antarctica.htm
[134] George, A., (2004)
[135] ibid.
[136] ibid.
[137] Laws, R.M., (ed), (1984). 'Antarctic Ecology: Volume One'

Opinion regarding the validity of the accretion ice organisms is somewhat divided. Some argue that low temperatures and extremely high oxygen levels mean that the lake is incapable of supporting life[138]. The extreme isolation of the lake means that any metabolic waste products, such as oxygen, will build up in the lake with no place to go. It is thought that the micro-organisms found in the accretion ice may in fact be contaminants from the unsterilised drilling equipment[139]. Many of the species identified in accretion ice samples are common laboratory contaminants[140].

On the other hand, in the accretion ice, two to seven times as many organisms were found as in the overlaying glacial ice, indicating the lake as a source of micro-organisms[141]. Researchers are convinced their decontamination efforts are effective and that the organisms identified originated from the ice. In regard to oxygen toxicity it is possible that the lakes may demonstrate stratification of oxygen much like in the dry valley ice capped lakes. Anoxic bottom waters could provide a refuge from the oxygen toxicity in the upper layers.

The truth of the matter will remain in question until the drilling enters the lake proper. There is some concern that the dirty drill hole could result in contamination of the lake and make determining if there are endemic micro-organisms in the lake very difficult. However, politics are not the focus of this report. Provided the lake is entered cleanly, the results either way are of great relevance to this matter. If life could exist isolated under Earth's frozen ice cap for 15 – 30 million years then perhaps it could exist under Mars' also. On the other hand, if nothing has survived in Lake Vostok then it is unlikely to have survived a similar location on Mars.

[138] George, A., (2004)
[139] ibid.
[140] ibid.
[141] ibid.

## Breaking down the Martian Analogy

Ancient Earth and Mars may once have been similar but early on their paths diverged. The atmospheric compositions of the two planets are now very different. The Martian atmosphere is mostly $CO_2$ (95.32%) with small amounts of $N_2$ (2.7%), Ar (1.6%) and $O_2$ (0.13%)[142]. On Earth, the development of the oxygenic photosynthetic bacteria resulted in the profound evolution of $O_2$ into the atmosphere. Earths atmosphere is composed of primarily $N_2$ (78.08%), $O_2$ (20.94%), Ar (0.93%) and $CO_2$ (0.035%)[143]. The development of an ozone layer resulted in significantly reduced surface UV flux. The seasonal formation of the ozone hole over Antarctica means that from spring and over summer, organisms are exposed to twice the UV radiation as elsewhere on Earth[144]. Being further from the Sun, Mars receives less incident light, but has essentially no UV protection. The UV flux at the surface is significantly higher then anything experienced on Earth including in Antarctica during the worst of the seasonal ozone depletion.

The surface pressure on Mars varies with season and location but peaks at around 10mb[145]. The atmospheric pressure in Antarctica and over the rest of Earth is about 100 times as high. The thin atmosphere on Mars means that there is no greenhouse effect and thus daily temperature variations are significant. During the southern summer, day/night temperatures at lower latitudes vary by over 90°C and peak at up to 25°C[146]. In the North, temperatures get close to, but never really cross over 0°C[147]. (See Figure 6) In Antarctica, similar if slightly less extreme temperature changes may occur over the period of a year but certainly not on a daily basis.

[142] Carr (1981). ‘The Surface of Mars’
[143] Online Encyclpedia, Wikipedia
[144] Onofri et al, (2004).
[145] Carr (1981). ‘The Surface of Mars’
[146] ibid.
[147] ibid.

### *Dry Desert Pavement*

The Antarctic dry desert pavement is an extremely hostile environment and the small quantity of organisms that survive those conditions is evidence of that. The Martian dry desert pavement is much worse. There, the effects of all of the differences mentioned above are experienced. Anything living in especially the top few centimetres of the soil would be subject to a low-pressure environment, massive daily changes in temperature and significant UV flux. Organisms barely survive the harshness of the Antarctic soil and in many ways do not appear to actually *live* there. Could anything survive the Martian conditions? Simply extending the Antarctic analogy the immediate answer is no. Life can barely survive Antarctica, it could not survive Mars. However, the problem is a little more complicated than that. Organisms in the Antarctic desert do not appear to have acquired a great deal of specific adaptation, but the Martian desert has existed for a great deal longer and spans a much larger area. In addition there are not any 'more favourable climes' from which organisms may be blown. Continued existence on the planet would have meant adaptation to conditions as they approached current. Anything existing in the Martian dry desert pavement *must* exist there due to a high degree of adaptation. We cannot use the Antarctic lack of endemism as a model for a similar lack of endemism on Mars.

While our Antarctic organisms do not experience as large a UV flux as is on Mars, many do have adaptations for coping with UV, pigmentation being the most common[148]. What is more, on Earth, before the advent of the ozone layer, photosynthetic bacteria were thriving, and Earth received a greater dose of UV than Mars due to its closer solar proximity. The UV flux on Mars, while presenting a photobiological challenge, does not preclude the existence of life. The temperature extremes experienced on Mars on a daily basis are more acute then the Antarctic extremes of temperature experienced over a year. These huge changes in temperature put significant strain on most species and the majority of Earth based organisms are unlikely to survive over

[148] Wynn-Williams and Edwards, (2000).

the long term. However, the huge fluctuations in temperature only affect the top few millimetres of the surface. Changes in temperature rapidly become less and at depths of about 20 centimetres the temperature rapidly converges on the diurnal mean[149]. In addition, some Earthly organisms have strategies to cope with continuously changing temperature and it is possible that, considering the time period, a Martian organism could have evolved techniques to cope with even the surface extreme.

Low pressure can affect cell structures and bio-membrane permeability[150] and it also means that molecules of atmospheric gas are in short availability. However, a number of Earth based bacterial species have been shown to survive long term incubation under low pressure, or even in vacuum[151]. Many spore forming species can survive a period under vacuum. Incubation of Antarctic soil in medium-high vacuum for 3 years showed a high proportion of *Corynebacterium sp*, which are non-spore forming[152]. The low pressure reduces the chances of finding extant life in the Martian soils, but does not make it impossible. However, what the low pressure also results in is instability of liquid or frozen water on the surface[153]. The temperature may get high enough, especially in combination with solar heating of the ground, for liquid water to exist but the low pressure negates this. Precipitation is zero at lower latitudes and is predominantly $CO_2$ at the poles[154]. No water means no metabolism. The question therefore is; could anything in the soil survive long term dehydrated dormancy?

Dose et al looked into the possibility of certain organisms surviving in a dormant state for geological time periods of dehydration[155]. Anhydrobiotes survive arid environments by a number of strategies such as accumulation of polyols or non-reducing saccharides, which help reduce membrane and

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[149] Horneck, G., (2000)
[150] Bucker et al, (1972)
[151] Cameron and Conrow, (1971) *JPL Technical Report 32-1524*
[152] ibid.
[153] Carr, M.H., (1996). 'Water on Mars'.
[154] ibid.
[155] Dose et al, (1995).

protein damage[156]. But low water partial pressure results in an accumulation of various lesions on DNA, such as strand breaks and cross-linking[157]. If the damage is not too extreme then it appears that it can be repaired after rehydration before the first step of replication; however, long periods without hydration allow greater accumulation of lesions and less chance of successful repair[158]. In an environment such as the Martian dry desert pavement which also contains the additional DNA and protein stress factors of UV light, temperature variations and possibly oxidative soil, dehydration dormancy for geological time periods is extremely unlikely.

There are no guarantees that a Martian biology will behave in a similar way to Terran biology; indeed, exobiologists do not expect to find all the same molecules. But they do expect to find similar molecules that do not necessarily act in the same way, but in similar ways. If we do not expect this, if what is expected is something completely different, then there really is absolutely no point in using models. The point here is, we could argue that Martian organisms may have found a way to cope with geological periods of dehydration, but the work of Dose at al suggest that there is a limit to what can be done given the molecules involved. Periods of hydration and metabolic activity are needed if DNA or something similar to DNA is going to be repaired. Water is the life limiting factor for the dry desert pavement organisms and the Martian availability is just too limiting to expect anything to survive.

[156] ibid.
[157] ibid.
[158] Dose et al, (1995).

### *Cryptoendolithic Communities*

Many of the key differences between the environment in the dry valleys and the environment on the Martian surface are mediated by the cryptoendolithic habitat. The steep light gradient that exists in the top few millimetres of the sandstone rocks would also greatly reduce the amount of UV radiation and the absorptive power of these rocks for atmospheric gases would serve to concentrate the important metabolic gases despite the very low surface pressure[159]. The Antarctic cryptoendolithic communities are necessarily oxygenic photosynthetic, given that the environment is aerobic while any such communities that may exist on Mars would necessarily have to be anoxygenic photosynthetic given that the Martian environment would be largely anaerobic. However, this would likely not place any significant barrier to the formation of these types of communities; at least, none that can be predicted based on any Earth based models. They would be different to those on Earth in terms of biochemistry but similarly adapted to the particular environment.

One environmental factor that does make a difference is that of low precipitation versus no precipitation. In the Antarctic model these organisms cope with the low availability of water by retreating into a habitat that maximises the water that is available. On the surface of Mars precipitation is nil. The reduced pressure may not be so important in terms of the effects of low pressure on organisms so much as, once again, the stability of water. An endolithic habitat cannot maximise zero water to anything useful. Water is the single most important limiting factor for such living systems. The complete absence of it on the surface of Mars and considering the work of Dose et al on surviving long periods of dehydration, it seem extremely improbable that any such communities could be extant on Mars today.

But all is not lost with the cryptoendolithic model. It is possible that, as the availability of water decreased, conditions earlier in Mars' evolution were such that cryptoendolithic communities were an important habitat. If this were the

[159] Bizony, (1998). 'The Exploration of Mars: Searching for the Cosmic Origins of Life'

case then the questions must be asked: ‘what remnants of their existence might there be?’ and ‘where would we look for them?’ The exfoliative weathering produced by the activity of these communities on Antarctic rocks is just as likely to occur in the Martian environment and the rock formations resulting from this process are an important fingerprint of the Antarctic communities. Could such structures have survived for the last few billion years? On Earth this is unlikely, but on Mars, especially in the older southern hemisphere, there is the potential for such structures to have survived. If this is the case, there are not likely to be any cellular structures preserved and the rock forms would perhaps not be considered sufficient evidence for the past existence of endolithic communities.  Chemical remnants such as carbon isotope ratios, or bio-minerals would be important for establishing the actuality of such macroscopic structures as remnants of life.

### *Antarctic Ice Covered Lakes*

It is a well-established fact that atmosphere and water chemistry are closely linked. While it is true that ice caps isolate lakes from the atmosphere to an extent it is a simple fact that Martian waters are going to be fundamentally different to Terran waters. In Antarctic ice covered lakes oxygen plays a major part in the water chemistry. On Mars, with a predominately $CO_2$ atmosphere past and present, carbon dioxide would play a much more significant role and in all likelihood oxygen would be extremely minor. One major effect on water by $CO_2$ saturation is a depression of the pH. Fresh water saturated with $CO_2$ has a pH of 5.6[160]. It is difficult to predict exactly what effect the altered water chemistry would have on life within such lakes and obviously our models cannot help in this respect. However, the earliest life on Earth, and more than likely on Mars, was anoxygenic. It photosynthesised without oxygen production[161]. While such lakes would contain organisms with quite different metabolisms to those seen in Antarctic lakes, this does not preclude their existence.

Paleolakes with sedimentary basins are one of the best hopes for finding ancient Martian fossil based on the stromatolite formations seen in Antarctic lakes. Given their probably quite different biochemistries, could Martian lake organisms form stromatolites? Of course this cannot be known for sure unless investigators go and look and hopefully find such deposits, but in the interim, consider: ‘Why do these laminated mats form in Antarctic Lakes?’ and ‘Is their any reason they would not form in Martian Lakes?’

The main reason for the formation of microbial mats in Antarctic lakes is lack of disturbance. The majority of organisms in these mats are cyanobacteria[162]. There may be some advantage afforded, such as UV protection, but in reality they just grow and do not go anywhere. In the absence of macro-organism such as grazing fish, the mats grow, accumulate minerals and sediments,

[160] Online Encyclpedia, Wikipedia
[161] Falkowski and Raven, (1997). ‘Aquatic Photosynthesis’
[162] Simmons et at, (1993)

move up above the inorganic layer generated and continue to grow[163]. As we are not expecting to find grazing animals on Mars, lack of disruption should not be a problem.

While the Antarctic microbial mats are composed of oxygenic photosynthetic organisms, many of these bacteria are capable of anoxygenic photosynthesis[164]. Not preferentially, but the biochemical pathway is there. There is no reason that the anoxygenic photosynthetic bacteria that are the likely inhabitants of such Martian environments would not also form microbial mats.

The only conceivable barrier to stromatolite formation on Mars would be introduction of sediments into the lakes. Once peak temperatures become too cold or rare such ice capped lakes could become ice sealed and sediment could no longer enter the lake[165]. Vida-esque lakes were probably the last stage before the Martian surface became entirely uninhabitable, but there is unlikely to be any fossil record for this time.

Provided the lakes remained accessible for a reasonable amount of time then the formation of stromatolites in Martian paleolakes is quite possible. For how long this was before lakes became ice sealed depends on how rapidly the planetary cooling occurred. An atmospheric collapse would be much faster then a gradual loss. The period before lakes became ice-sealed could have been quite short or very long[166]. In the south, present summer temperatures peak above 0°C on a regular basis and as this is also where the oldest surfaces on the planet can be located; any southern lake remnants would likely prove the most fruitful in this regard.

[163] Simmons et at, (1993)
[164] Falkowski and Raven, (1997). ‘Aquatic Photosynthesis’
[165] Doran et al, (2003)
[166] A more through elucidation of Mars’ water history is needed, though given the size of some of the layered deposits in the canyons a long period of sedimentary deposition is suggested.

### ***Microorganisms in the Ice Sheet***

The ice cap analogy is in some ways better than the desert analogies as a possible location for living or at least well-preserved microorganisms. Buried deep in the ice there is no exposure of this environment to any of the Martian conditions not experienced on Earth. Surface pressure is irrelevant at that depth; gases and salts are frozen out so water ice is water ice on either planet. Apart from the top few metres, light and UV penetration is zero and temperature variations non-existent as the temperature at depth approaches the mean of the region. This applies to both Antarctica and Mars, with the Martian mean annual temp being somewhat colder than on Earth.

There is one significant difference between the Antarctic ice sheet and the Martian ice cap, the respective ages of the ice within. The exact age of the Martian ice cap is not known, but the non-existence of a present day water cycle means that it would not experience the turnover of the Antarctic ice sheet. So while the very deepest layers of the Antarctic ice sheet are between 400,000 and 500,000 years old, the deepest parts of the Martian ice cap could conceivably be 3.5 billion years old. This is a very good thing for the exobiologists as if it were younger there may not have been any organisms to be carried to the ice sheet and frozen within. The disadvantage is that the Antarctic ice cores are not representative of the survivability of organisms for these time periods. The fact that the only viable organisms within the oldest Antarctic samples are spore-forming bacteria is important. It is clear that organisms would need some sort of extreme non-vegetative state to survive prolonged anabiosis and this would apply equally to Martian organisms. The fact that the Martian ice cap is colder than the Antarctic ice sheet is a point in favour of long-term preservation.

The research into the survivability of micro-organisms for geological time periods in a state of dehydration came to the conclusion that the half lives of dormant organisms would be much higher at low temperatures, especially as most chemical reactions cease at temperatures below 140°K[167]. In addition, preservation in the ice cap also protects from UV damage and the possible oxidising agents in the soil. If organisms were trapped in the Martian ice cap in a similar way to the way they were on Earth then it is conceivable that they could still be detectable in ice cores, despite the time period; and even if there are no viable organisms or even whole cells, there would likely be chemical remnants such as DNA fragments[168] (or the Martian equivalent).

The type of organisms found in the Antarctic ice sheet demonstrates the possibility that they may be blown in form other locations on the planet. A similar process could have occurred on Mars so even if there were no indigenous microbial communities in the high north, microorganisms from lower latitudes could have been preserved. Exploring ice cores from the Martian ice cap could provide an indication of the presence of life in other parts of the world.

An environment similar in many ways to the thick water ice of both Earth's and Mars' ice cap is the theorised high latitude permafrost. Dark and very cold, organisms could possibly have been preserved in a similar way. Studies on permafrost cores have focused on the Siberian permafrost up to five million years old, from which viable organisms have been retrieved[169].

[167] Dose et al, (1995).
[168] ibid.
[169] ibid.

### *Sub-Glacial Lakes*

Similarly to the ice sheet analogy, Martian sub-glacial lakes would be mostly unaffected by the significant environmental differences between Mars and Antarctica, pressure, UV flux, temperature variations, although the water chemistry of any sub-glacial Martian lakes would reflect the $CO_2$ atmosphere.

Again, there is a significant age difference. The Antarctic sub-glacial lakes are believed to have been isolated for the last 15-30 million years, while if any such lakes are present on Mars they would have been isolated for several billion years. However, if it is possible for an ecosystem of this sort to exist isolated for 30 million years then is there any reason to think one could not exist for 3 billion years?

Of course the existence of such lakes on Mars and the presence of an ecosystem within Lake Vostok have yet to be established but a result for the positive would be very informative. Even the negative existence of an ecosystem in Lake Vostok would not entirely rule out the possibility of life in a similar environment on Mars. One of the main objections to life in Vostok is the possibility of toxic concentrations of oxygen in the lake water. The differences in atmospheric composition and thus water chemistry mean this is unlikely to be a problem for any such Martian lakes. If Vostok did turn out to be lifeless and the isolation of the system was thought to be the reason then this would imply that other lakes under similar states of extreme isolation would be unlikely of harbouring life; however if the oxygen was to blame that would be a different matter.

If a sub-glacial lake were found to be present on Mars, the rare example of liquid water would be worth exploring and while the biological state of Lake Vostok is not yet known for certain, if it were sterile, it would be the only such body of water on the entire planet.

### *The Value of Being There*

In the Antarctic model there is one other significant difference that confers a great advantage in looking at the Earth based systems over the Martian, the ability to go there in person. The use of remote probes is simply not as good as having live people capable of making on the spot decisions on where to go next, or what to do, which rocks to crack open, based on much more detailed information. The results of the Viking Mars Lander tell us that much.

The Viking Lander contained a GC/MS that could not detect the presence of any organic molecules in the Martian soil. This was considered the deal breaker experiment for Viking. The other three biology experiments produced somewhat odd but apparently positive results. The popular explanation now for the Viking biology box results is the presence of reactive oxygen species such as $H_2O_2$ in the soil. This has not actually been confirmed and in many ways does not make sense as these chemicals are very reactive and the UV flux at the surface should have broken down any such species in the soil.

Antarctica can act as a model for probe use; indeed, Mars rover testing was done in Antarctica as were the Viking biology box experiments. But it can never predict all the variables or conditions, Such as how to interpret odd results like those from the Viking biology box, and if something goes wrong with a probe in Antarctica you can go and fix it. There is only one chance to get it right on Mars[170].

[170] Unless you have a backup in which case you may have two chances and no guarantee that that will be enough.

## Conclusions

Are the Antarctic based, Martian analogies perfect? No, not by any means. Are they useful? Certainly! These analogies, and others on Earth, provide important insights into potential extraterrestrial habitats. *They do not describe such habitats*. It is important to realise the limits to these analogies. By understanding the differences between the Antarctic habitats described and the potential Martian analogues, such variations that exist can be incorporated into theoretical habitats and ecologies and greater insight into said extra-terrestrial habitats is obtained.

It may be that some differences do not matter as much, such as the atmospheric composition and consequent variations in biochemistry, while others fundamentally alter the situation, such as atmospheric pressure, water stability and low precipitation verses no precipitation. The Antarctic based Martian analogues are important guides for the search for life on Mars, but it is only by a proper understanding of them, and their limitations, that the most useful information can be attained.

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