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Does Life on Earth Imply Life on Mars?

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DOES LIFE ON EARTH IMPLY LIFE ON MARS?

This essay is an outline of the current theories for the origins of life on Earth, and explores the question of whether life might have arisen and evolved on Mars at the same time as it did on Earth. The essay concludes with a discussion of the implications of life being present on, or of life being absent from, the surface of Mars.

Introduction

This essay is an essay of two halves: the first is a very general outline of what is known about life on Earth, how it might have originated and where it is found. Also included in this part of the essay is a description of Mars, its physical characteristics and surface environment and a consideration of where on Mars we might expect to find life. Evidence for these observations comes from a combination of space exploration missions and laboratory analyses of meteorites from Mars. The second part of the essay is more discursive, and is a combined discussion and almost completely speculative opinion piece about the consequences of finding, or not finding, life on Mars.

What is life?

Before we embark on any discussion about the presence or absence of life beyond Earth, it is useful – indeed, necessary – to have a 'working definition' of life, in order that we might have a frame of reference against which to judge observations. It is difficult to find a completely satisfactory definition of life. As Carl Sagan remarked: 'The search for extraterrestrial life must begin with the question of what we mean by life. "I'll know it when I see it" is an insufficient answer' (Sagan, 1994).

Biological definition: At school, students are taught that there are seven characteristics of living beings: growth, reproduction, respiration, nutrition, excretion, locomotion and response to external stimulus. However, this is by no means a complete description of something that is alive. For instance, the properties of fire might all be fitted into this description: as long as there is fuel (nutrition), a fire will grow, move, take in air, give out heat, respond to wind direction and so on. But we would never describe a fire as being 'alive.' Conversely, would we describe a virus as alive? A virus is a microscopic organism that consists of a core of nucleic acids surrounded by a sheath of proteins. Although a virus has the potential to grow and reproduce, it does not contain the necessary cellular components to do so by itself: it needs a host. Viruses are parasites – they are living organisms, but cannot sustain life independently from their hosts. In any search for life, it is unlikely that we would find viruses alone – they would always be associated with their host organism.

The most widely accepted definition of life is that put forward by G. F. Joyce: 'life is a self-sustained chemical system capable of undergoing Darwinian evolution' (Joyce, 1994). Joyce's definition regards the ability to adapt and to evolve independently as being necessary characteristics of viable living beings. Implicit in this definition is an understanding that information is transferred from one generation to the next. This transfer of information is the process of inheritance and is a way of recognising something that is capable of adapting and evolving.

Ethical definition: The definition of living organisms as those that could adapt and evolve independently is a mechanistic approach that does not consider what might be regarded as 'higher functions,' such as consciousness, rationality, altruism, etc. Is there a difference between a living organism and a conscious one? At what stage in evolutionary history did organisms develop consciousness? This question harks back to the debates that followed Darwin's publication of *On the Origin of Species* in 1825, and is fundamental to our understanding of life and its development on Earth. To argue that an organism must be conscious before it can be regarded as 'alive' is a contention that will draw us down the murky path of medical ethics, leading towards consideration of the rights (or otherwise) of a foetus, decisions about termination of life-support systems for patients in a persistent vegetative state, etc. Whilst there is no doubt this is an extremely interesting and difficult subject area, it is probably not completely germane to a debate about implications for life on Mars.

In contrast to the concerns of medical ethicists, the field of environmental ethics moves away from considerations about consciousness. It widens the boundaries of what is thought to have value, to encompass what is generally regarded as non-living: 'one of the most important ethical issues raised [...] has been whether nature has an order, a pattern, that we humans are bound to understand and respect and preserve. [...]' (Worster, 1985). Pursuing this line of reasoning brings us to what an ethical definition of life might include. Philosophers have long recognised that an object can be valued for itself (*intrinsic* value) and not because of its purpose (*instrumental* or *extrinsic* value). Thus one of the first environmental ethicists, G. E. Moore, wrote: 'It is necessary to consider what things are such that, if they existed *by themselves*, in absolute isolation, we should yet judge their existence to be good' (Moore, 1922). If we follow this guidance, then any entity that fulfils Joyce's definition of life has an intrinsic value, and we must be aware of this when investigating the possibility of life on Mars.

Molecules to Man

Steps towards the origin of life

In order to investigate how (and where) life originated on Earth, it is instructive to step through the sequence that is now widely accepted as the most complete explanation that we currently have for life's origins. We do not know with absolute certainty the precise details or mechanisms, but first Oparin (1936), and independently Haldane (1929), outlined a sequence of events that started with the abiotic synthesis of simple molecules, possibly brought to the early Earth from space. Miller (1953) carried out a series of experiments that showed very successfully that a mixture of simple molecules such as H_2, H_2O, NH_3 and CH_4, when exposed to a spark discharge, could form more complex molecules, including amino acids. These experiments were among the first indicators that biologically-significant molecules could be produced from inorganic starting materials by abiogenic processes.

For life to materialise, the organic molecules must self-organise, such that they become a unicellular organism. This is not a simple step – it is a giant leap. Even the simplest of such organisms contain specialised sub-units (organelles): the cell nucleus, a cell membrane or wall, a chloroplast in the case of plants, etc. So the gap between molecules (even one as complex as DNA) and unicellular organisms is immense. Two important advances were necessary before the collection of chemicals could become a cell: development of a membrane (Deamer, 1998) and the ability of the components to replicate (Joyce, 1989). It is not certain whether these changes occurred in parallel, or whether one preceded the other. Focussing first on production of a membrane. A membrane is required to enclose the components of a cell and to provide a discrete space in which reactions can take place. It forms a barrier across which nutrients and waste products move. A cell membrane is usually composed of a double layer of amphiphilic molecules, i.e. organic molecules that have a hydrophilic head and a hydrophobic tail. The water-repelling ends of the molecules face inwards towards each other, leaving the polar heads of the molecules in contact with the surrounding (aqueous) environment. The lipid bilayers can close up to form a vesicle, which is capable of holding fluid – indeed, amphiphilic molecules have been proposed as potential precursors of life in a 'Lipid World': 'We propose that crucial steps in the origin of life might have been carried out by lipid-like molecules alone, potentially prior to the emergence of polynucleic acids and polypeptides' (Segré et al., 2001). Structures based on a similar association of molecules have been isolated from carbon-rich, primitive meteorites, indicating that vesicles can form by abiotic self-assembly (Deamer, 1985).

Self-replication is the other necessary stage between prebiotic chemistry and biogenesis. A widely-accepted description of how this stage might have been achieved is the idea of an RNA world (Gilbert, 1986). The RNA molecule is a single-stranded helix, composed of four bases (adenine, cytosine, guanine and uracil), and capable of self-replication; it also acts as its own catalyst for this reaction. Once a molecule such as RNA has formed, given an adequate and appropriate feedstock and an amenable environment (ample time, energy and stability for reactions to occur), then continuous replication by autocatalysis can take place (Joyce, 1989). In such a scenario, the specific location of the reaction has not been defined: it is likely to require a surface, so that the molecules have a higher probability of interacting. This surface could well be a rock or mineral, with the mineral acting as a surface catalyst, where organic molecules bind to the clay surface through displacement of exchangeable divalent metal cations (Ferris, 2005).

Cairns-Smith also posited an era where reactions between organic compounds were catalysed on the porous surface of clay minerals. But in this case, the clays acted as a scaffold to build up molecules until they were sufficiently robust to exist without the supporting structures (Cairns-Smith, 1982). This is a different function from how a mineral is perceived to have been involved in prebiotic chemistry in the RNA world. An alternative point of view has been espoused by Günter Wächtershäuser, who argued that development of a metabolism was a more fundamental step in the origin of life than either development of a membrane or the ability to self-replicate: 'We have to guide the construction of a theory on early evolution so as to explain the greatest number of facts of extant organisms with the smallest number of evolutionary assumptions' (Wächtershäuser, 1990). He envisaged a world in which iron sulphide (pyrite) acted as a catalytic surface. Gases (CO, H_2S) dissolved in water flowing over the surface would react with the iron sulphide, and become fixed, forming organic molecules, which themselves reacted with the gases, producing ever-larger molecules, including sulphur-bearing organics (thioesters), which are known to be important in present-day metabolic cycles (de Duve, 1998).

We are now at the stage where abiotic mechanisms have been suggested and modelled for the production of a cell membrane, molecules that can self-organise and self-replicate, and a chemical system capable of metabolism. Beyond this is biogenesis – and possibly the point at which evolution begins. When Darwin first formulated his 'theory of descent with modification through natural selection' (Darwin, 1859, p. 371), he envisaged a continuous smooth progression whereby a species or population gradually and imperceptibly changed: 'As natural selection acts solely by accumulating slight, successive favourable variations, it can produce no great or sudden modification; it can act only by very short and slow steps' (p. 380). The identification of gaps and bridges in the fossil record necessitates a more irregular evolutionary progression – either punctuated equilibrium (Eldredge and Gould, 1972) or punctuated gradualism (Malmgren et al., 1983) – whereby a species remains unchanged (in stasis) for most of its history, before going through a rapid (on a geological timescale) evolutionary adaptive change. This may lead to development of a new species (punctuated equilibria) or not (punctuated gradualism). As Stephen Jay Gould, one of the original proponents of punctuated equilibrium wrote: 'The history of life is not necessarily progressive; it is certainly not predictable. The earth's creatures have evolved through a series of contingent and fortuitous events' (Gould, 1994). This statement explicitly includes the role of chance – although catastrophic impact with the Earth of an asteroid several kilometres in diameter does not so much punctuate (or even puncture) the equilibrium of evolution, so much as completely rupture it.

The fossil record is complemented by a biological record: the rise of cladistics (classification of living organisms on the basis of shared characteristics) and the use of genetic sequencing have together become a powerful tool by which evolutionary relationships between extant species and groups of species can be traced. This has led to illustrations, such as that in Figure 1, of a Tree of Life, in which groups of species can be organised. Charles Darwin is generally credited with sketching the first Tree of Life showing progressive relationships between organisms (Darwin, 1837). Looking at the arrangement of species in Figure 1, it is always a salutary experience to note the proximity of animals to slime moulds, a reminder indeed of our forebears! In the final chapter of *On the Origin of Species*, Charles Darwin summarised his hypothesis that life came from a single ancestor 'Therefore I should infer from analogy that probably all the organic beings which have ever lived on this earth have descended from some one primordial form' (p. 391). (It is interesting to note that whilst this sentence is widely quoted as evidence for Darwin's breadth of vision, the final clause of the sentence is frequently omitted: 'into which life was first breathed by the Creator.')

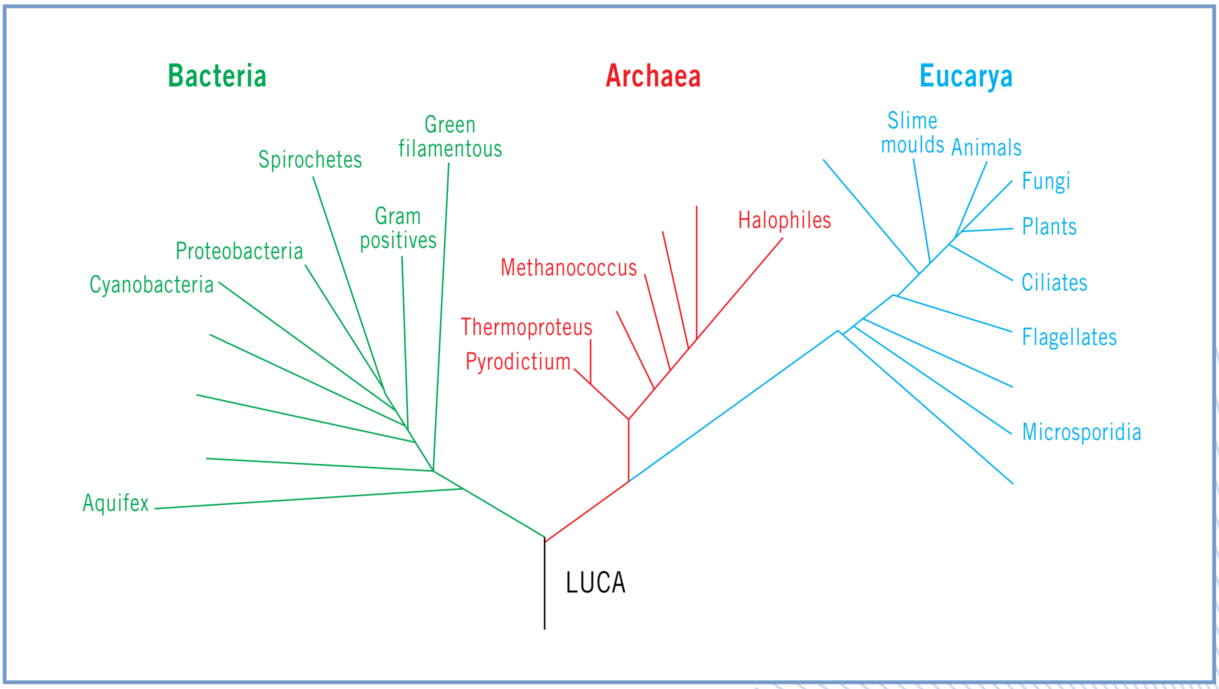

Figure 1: A depiction of the Tree of Life based on 16SrRNA sequencing, showing the three main domains, or kingdoms, into which life-forms are classified (Woese and Fox, 1977). LUCA – Last Universal Common Ancestor, a hypothetical organism from which all other living beings are assumed to have evolved (Woese, 1998).

Recent advances in understanding of evolutionary history have shown that the Tree in Figure 1 is far too 'unidirectional' – there is an inherent implication in its construction that all change occurs in the vertical direction, moving upwards and outwards along the branches. There are, however, many cross-over links between the Bacteria and Archaea, where horizontal transfer of genetic information has taken place between otherwise unrelated organisms (Brown, 2003). It is also possible that horizontal gene transfer was significant in the development of components within the cells of plants and animals (e.g. Kurland and Andersson, 2000; Martin et al., 2002). It looks as if the Tree of Life may be more like a hedge.

Despite the complexity of the evolutionary record, it is still possible to trace back to our 'Last Universal Common Ancestor' (LUCA; Figure 1), which was probably not an organism in the way we currently understand an organism to be. Carl Woese, who first recognised that unicellular organisms formed two main branches (domains, or kingdoms) of the Tree of Life, rather than one, described the LUCA as follows: 'The ancestor cannot have been a particular organism, a single organismal lineage. It was communal [...] a loosely knit, diverse conglomeration of primitive cells that evolved as a unit, and it eventually developed to a stage where it broke into several distinct communities, which in their turn become the three primary lines of descent' (Woese, 1998). The LUCA is where 'evolution' *per se* begins – where adaptation to the external environment can be traced through the branches of the Tree of Life. Discussion in this section has focussed on the mechanism that propelled prebiotic chemistry into biochemistry. Even though some of the mechanisms described rely on inorganic templates or substrates as fore-runners of the LUCA, it is clear that once a certain step is reached in the pre-evolutionary history of life, organic molecules become an essential component of the sequence. What determined that organic chemistry would have such a central role in biotic synthesis, and in life itself?

Requirements for life: the roles of carbon and water

All life on Earth is carbon-based: carbon has an atomic structure that imparts unique properties to the element. It can form chains and rings of atoms, giving rise to an infinite host of organic compounds capable of solution in either polar or non-polar solvents, depending on the composition of attached functional groups. No other element has the ability to produce stable chains and rings in this way. The only element that approaches carbon in its versatility is silicon, which forms extended chains, rings and polyhedra when combined with oxygen. The Si-O bond is the basis of the vast inorganic chemistry of the rock-forming minerals; clay minerals have been proposed as possible templates for a mineral-based origin of life (Cairns-Smith, 1982), but the hypothesis is not widely accepted. If, for the reason of its atomic structure, carbon is the basis of life on Earth, then it is perhaps a logical assumption to make that it is also the basis of life elsewhere in the Solar System.

One of the dogmas surrounding discussions of the origins of life is that water is essential for life. This is rather misleading: the presence of water is not a necessity – but the presence of a suitable solvent is. At the cellular level, a solvent is required for several purposes: to dissolve and transport salts (nutrients); to enable removal of waste products; to act as a medium in which molecules are brought together to enable chemical reactions to occur; to keep cells firm and (in plants) to maintain rigidity of cell walls. The properties of water (a polar solvent, stable over the same temperature range as pertains at Earth's surface) are such that it is the most versatile solvent we have on Earth. And so liquid water is deemed to be necessary for life on Earth and, by extension, necessary for carbon-based life elsewhere.

Where on Earth did life originate?

> 'But if (and oh! what a big if!) we could conceive in some *warm little pond*, with all sorts of ammonia and phosphoric salts, light, heat, electricity, etc. present, that a protein compound was chemically formed ready to undergo still more complex changes [...]' (Darwin, 1871).

The well-known quotation from Charles Darwin is an almost unavoidable opening for this section. The warm little pond is a beautiful description that has served for many years as an outline for where pre-evolutionary processes might have occurred. We have already considered the importance of water as a solvent or transport medium in the steps leading up to the formation of biotic molecules. It is therefore probable that life originally emerged from a watery environment – but whether from surface waters or the deep ocean floor is not known. Until fairly recently, the likely energy source for pre-biotic reactions was thought to be the Sun, implying that surface waters were where organisms first originated. The deep ocean is now also favoured as a potential site for the origin of life, particularly around hydrothermal vents (Francheteau et al., 1979; Corliss et al., 1981). Here, energy for chemical reactions abounds (Edmond, 1982), and iron sulphide and clay minerals are present, either (or both) of which could acts as catalysts for the production and fixing of organic molecules in the first step towards unicellular organisms, although there are problems with this hypothesis (Miller and Bada, 1988). Recognition of hydrothermal vents as having developed ecosystems based on chemical, rather than photosynthetic energy, has led to the interesting possibility that life might also have arisen in the ice-covered ocean that envelops the surface of Jupiter's satellite, Europa (Carr et al., 1998). Wherever it first took place, life appears to have arisen on Earth almost as soon as it was possible to do so – traces in the fossil record date back to at least 3.5 Gyr (Brasier et al., 2006), a gap of only ~1000 Myr from accretion and differentiation of the planet. In the time intervening between the emergence of life and the present day, there has been colonisation by microbes of every environment in which it is possible for life to survive.

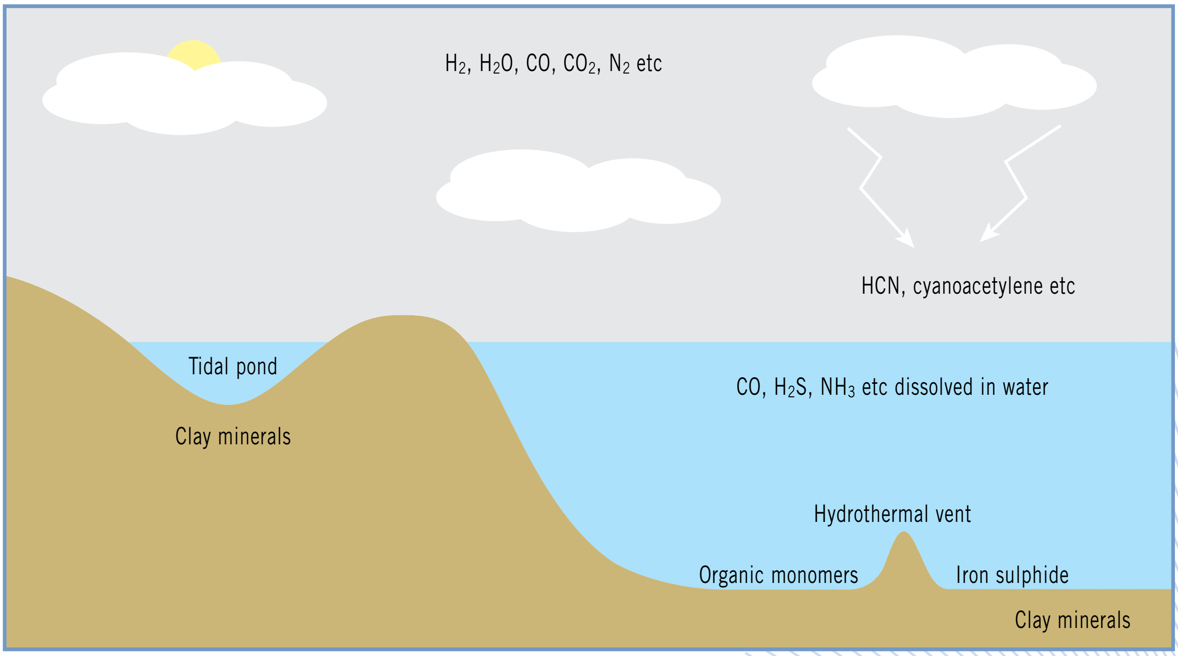

Figure 2: Schematic illustration of potential sites for the origin of pre-cellular entities.

Habitats for Life

Habitats on Earth

We now know that micro-organisms are able to exist – and even to flourish – in habitats that would, under ordinary circumstances, be considered as uninhabitable. Micro-organisms that occupy unusual habitats (extremophiles) are widespread on Earth. The biological envelope that encompasses their environmental range reaches from the most acidic of waters to the most alkaline, and from below the freezing point of water to well above its boiling point (Rothschild, 2009). The microbes that inhabit the different niches are not all the same species – they are not even of the same direct lineage, but cut across the two prokaryotic domains into which life-forms have been organised (Woese, 1998). What the organisms have in common, though, is a remarkable adaptability, variations on the regular cell structure or metabolism that enable their survival in otherwise hostile environments.

Looking again at the Tree of Life (Figure 1) – extremophile micro-organisms are on the lower branches – implying a fairly lowly evolutionary state. If evolutionary state is related to distance along a branch – as would follow if evolution were progressive – then extremophiles have only travelled a short distance since they first appeared at least 3000 million years ago (Fitch and Margolaish, 1967). This immediately brings us to the question of whether such micro-organisms might have evolved over a similar timescale on a neighbouring planet? And if so, might they still be in existence? These are valid questions: although the surface of Mars is indisputably hostile to eukaryotic life, there is no reason to suppose that extremophile micro-organisms might not be able to survive.

Habitats on Mars

There have been sufficient missions orbiting Mars and taking images of its surface that, had any higher, more evolved, forms of life been present, they would have been observed by now. So, no trees or rabbits or birds. But that still leaves plenty of scope for smaller creatures. If life got going on Earth from simple inorganic molecules present in Earth's atmosphere, can we make the same assumption for Mars? Yes – Mars was formed from the same protoplanetary disk as Earth, and was bombarded for the first few million years of its history as a planet by the same type of asteroids and comets as Earth. Thus Mars possessed the same indigenous and exogenous volatile compounds as Earth. What about the next steps, which, on Earth, seem to have required water? For the first ~1.5 billion years of its history, there were extended episodes of aqueous activity on the Martian surface, with rivers, lakes and inland seas present for millions of years at a time (Hartmann and Neukum, 2001). There have also been reports of more recent fluvial activity, represented by seeps and gulley formation (Levy et al., 2010). So the criterion for the presence of water is also satisfied – and thus the conditions for a pre-evolutionary, abiotic development of complex organic molecules were in place on Mars at the same time as they were present on Earth. Some of the mechanisms that have been proposed to move chemistry into biology on Earth are also applicable to Mars at this point in its history – although there is no evidence that hydrothermal vents (powered by underlying tectonic activity on Earth) were ever present on Mars. If we are correct in our understanding of the first stages in the origins of life on Earth, then there is good reason to suppose that these stages could also have occurred on Mars. Say life got as far as the equivalent of a Last Universal Common Ancestor. Did it evolve any further? By the time that multicellular organisms were expanding in range and diversity on Earth, Mars had lost its atmosphere, and so water was no longer stable on its surface. Clearly, we are not considering a community of canal-building artisans, as were believed to exist by the astronomer Percival Lowell: 'That Mars is inhabited by beings of some sort or other we may consider as certain as it is uncertain what those beings may be' (Lowell, 1906). But how far up the evolutionary sequence might have a Martian life-form advanced? We need to consider what Mars is like today, and what habitats might exist. Mars is ~230 million kilometres from the Sun (Earth is 150 million km); sunlight intensity decreases with distance, and the light that illuminates the Martian surface is between a half and a third as powerful as that which bathes the Earth. However, the factor that influences the Martian surface conditions is not so much the strength of the sunlight, but the absence of an atmosphere. Earth's atmosphere (~1000 mb pressure) acts as a protective blanket: it attenuates cosmic and solar radiation and insulates the surface from extremes of heat and cold. Without the atmosphere, and its ability to absorb infrared radiation, the mean surface temperature of the Earth would be around -20°C, rather than the current +15°C. Contrast this situation with that of Mars, which has a much thinner atmosphere, ~6 mb, and a mean surface temperature of ~-60°C, although temperatures can range from -130°C to +25°C (Kieffer et al., 1992). The tenuous atmosphere is incapable of blocking UV radiation from reaching the Martian surface, so Mars' surface is alternately hot and cold and is fried by UV radiation. It is also desiccated – bodies of standing water or streams of flowing water disappeared millions of years ago, along with the atmosphere.

Despite this hostile environment, there are niches on Mars that might host extant life. The observational evidence that the surface environment of Mars has been more amenable for life in the past inspired experiments on the *Viking* landers. Both craft had instrument payloads that included a gas chromatograph-mass spectrometer (GC-MS) and three separate biological experiments (Klein et al., 1976). The GC-MS was designed to test surface soils for the presence of organic compounds, and to identify them if present. The biological experiments were designed to test for metabolic action. Unfortunately, the results obtained were, on balance, negative (Klein, 1978). Although one of the experiments did give a positive signal that might have implied the presence of a metabolising agent, the overall conclusion from the mission was that there was no detectable trace of organic matter in the surface soils at either of the two landing sites, and thus no likelihood of the presence of extant life (Klein et al., 1992). Despite these conclusions, Mars has remained a prime target in the search for extraterrestrial life. We now know so much more about life on Earth than we did when the *Viking* experiments were designed, that we think it likely that surface soils are not the best place to search for signs of Martian organisms. One possible habitat is that analogous to that occupied by endoliths on Earth. These are groups of micro-organisms that live inside rocks. They form colonies just below the surface of rocks, along cracks and in fissures, and are lichens – a symbiotic association between unicellular green algae and filamentous fungi. They exist in both hot and cold deserts, including the Dry Valley region of Antarctica (Friedmann, 1982). Cryptoendoliths are able to survive extremes of temperature and drought, drawing on minerals from the rocks for nutrients. Such a symbiotic association might be pictured as colonising rocks on the surface of Mars. Living as they do within rocks, the micro-organisms would be protected from UV radiation. During the cold Martian nights, CO_2 from the atmosphere often forms a frost over the surface rocks. These could also freeze down traces of water from the atmosphere, providing sufficient liquid within the pore spaces of the rocks to maintain the frugal diet and glacial-speed metabolism of endoliths.

What are the implications if we do find life on Mars?

What will it mean if we do find life on Mars? Maybe it has already been discovered: there was an announcement in 1996 that a team of scientists from NASA had found non-terrestrial biological traces in the ALH 84001 Martian meteorite. The final sentence of the paper by Dave McKay and colleagues, who carried out the research, reads: '[...] we conclude that they are evidence for primitive life on early Mars' (McKay et al., 1996) – the type of life that might be colonising the surfaces of rocks and boulders on Mars in the same way as they colonise rocks and boulders on Antarctica. Whilst the claim to have found Martian life received a huge amount of publicity, it has not been generally accepted by the scientific community. The claim has never been withdrawn, and so it could be argued that traces of life have been found on Mars. There is currently little or no public discussion of the findings, so it seems as if life on Mars may be no big deal. That might also become the prevailing opinion if new results confirm that life on Mars is extant, or, even less-exciting, extinct. I suspect that, for many people, once the original excitement has died down, a certain feeling of disappointment or dissatisfaction might set in. If not quite expecting an H. G. Wells or John Wyndham type of alien, generations accustomed to Hollywood-style special effects may feel short-changed by reality: 'they spent billions of our money, and all they found were some bugs' could be a future headline. Beyond this, though, lies a wealth of questions. Are the micro-organisms related to terrestrial micro-organisms? If so, which came first, us or them? If they are not related, how can we be sure? How do they metabolise? Are they DNA-based? etc, etc. These are all compelling scientific questions, each one of which deserves its own essay to enable its full consideration. I will confine myself to one subset of these questions: the one in which there is indisputable evidence (whatever that might be) that the Martian life has an independent and separate origin from terrestrial life, and has a unique metabolism that is not based on DNA.

How do we view such an entity? How should we treat it? Does it have rights? Do we have responsibilities towards it? On one level, we could merely regard the entity as what it is: a micro-organism, and treat it as we do those on Earth: eliminate it if it is harmful, cultivate it if it is beneficial. Is this the correct attitude, though? A Martian micro-organism might be harmful to humans because its metabolism produces a toxic gas (say, for example, hydrogen cyanide), rather than the oxygen and carbon dioxide produced by plants and animals on Earth. Is this a reason to eliminate the organism? In his paper '*Microbes have rights*' (2004) Cockell argues that without microbes, there would be no life on Earth. He extends his argument to potential populations of micro-organisms on other planets (Cockell, 2005). The microbe has rights because it is – not quite the '*cogito ergo sum*' of Descartes, but certainly in sympathy with the tenets of environmental ethicism. If we accept these arguments for a terrestrial micro-organism, then there is an even more powerful case for the protection of Martian organisms. Not only do they have an intrinsic value, and thus a right to existence, they also have an instrumental value (Smith, 2009). This value comes in what we can learn from the Martian micro-organisms about their biology and ecology. This is more than an intellectual study of a living being, although that is certainly of interest. But how has this organism evolved along a separate pathway from life on Earth? What chemical pathways were favoured, and why? What strategies has it developed to mitigate the effects of a seemingly hostile environment? How has the organism evolved? How does it transfer information through generations? These are the types of questions that will illuminate comprehension of our own evolutionary history.

We can go beyond the micro-organisms, and, as would be thought proper by an environmental ethicist, consider the ecological niche of the micro-organism as being indivisible from the organism. So this brings us to the planet. If there is life on Mars, then the planetary environment, harsh and unforgiving as it might appear to us, is a habitable environment, and must therefore be respected in the way that we respect (or, at least, ought to respect) different ecological niches on Earth. Thus we declare sites to be of 'Special Scientific Importance,' recognise National Parks and Forests, and designate regions as conservation areas. These all receive protection from development. The Antarctic Treaty, negotiated in 1959, has operated for over 50 years, and still sets the behavioural limits for visitors to the continent (http://www.ats.aq/documents/ats/treaty_original.pdf). Maybe a similar type of UN-supervised international treaty would limit unrestricted and unrestrained access to Mars, safe-guarding the future, and the past, of potential micro-organisms.

Does consideration of a 'second genesis' impinge on the daily lives of the populace? Probably not. Does this matter? Again, probably not. What might have greater impact is if we find, against general expectations, that there is no life on Mars, and never has been?

Implications if we do not find life

As the previous section considered, there are several different opinions that might hold sway were life to be discovered on Mars. But what if the converse holds true, and Mars is declared to be sterile? Of course, it will be difficult to reach this conclusion without substantial and detailed exploration and analysis of the surface and sub-surface. But say, for arguments sake, that we have reached this conclusion. What implication does that have for life on Earth?

Before pursuing this line of enquiry, we should recap why we think life might have been viable on Mars. The planet had the building blocks for life, an atmosphere, water and sunlight. These ingredients occurred together for around 1000 million years before the atmosphere dissipated. So, on the face of it, and assuming a common mechanism, life should have emerged on Mars at around the same time as it emerged on Earth. Back to our question: what if life *did not* emerge on Mars? Does this imply that our models for genesis are incorrect? They are certainly incomplete – but sufficiently detailed to believe that the ability to break and make bonds between atoms is one of the major processes that must take place.

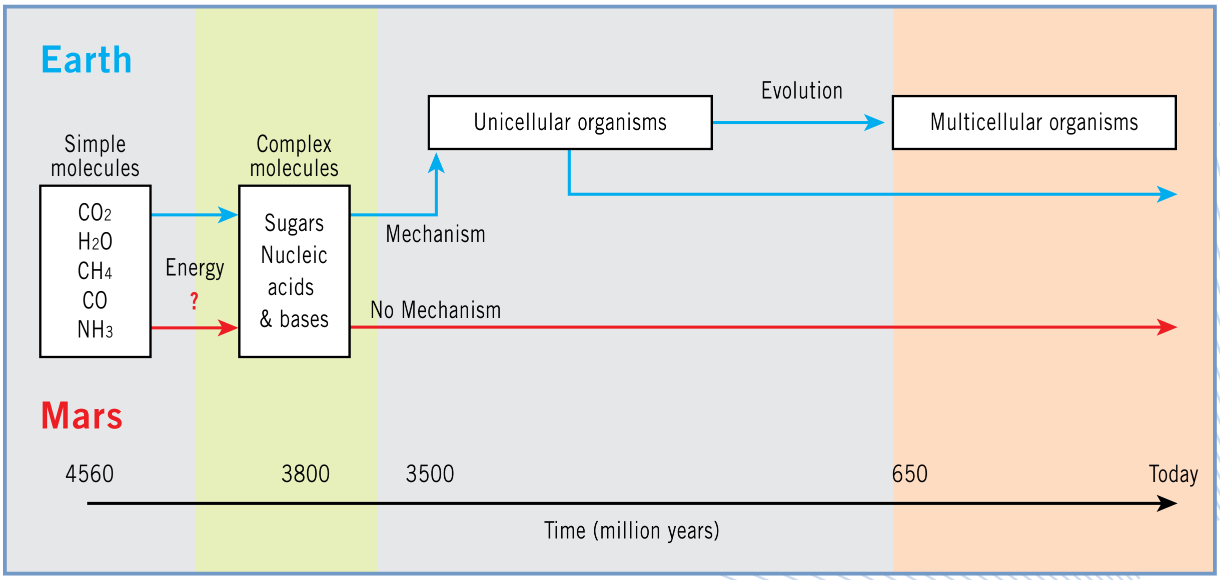

Figure 3: A schematic illustration of the pathway from simple molecules to complex organisms, contrasting the cases of Earth and Mars. The timeline is not to scale, and is only approximate.

Figure 3 is a highly schematic illustration of the processes involved in going from simple molecules to multicellular organisms. On the upper part of the diagram, 'Mechanism' is an unknown on Earth – there are theories, but this is still an incompletely understood part of the pathway to life. The lower part of the figure depicts Mars. As outlined in earlier arguments, the first stage, where simple molecules are present, is applicable to Mars. And although we have no evidence for their presence, more complex molecules should exist on Mars, since there was a source (the Sun) which could supply energy to break and make chemical bonds. It is the third stage, where molecules become a unicellular organism, which has not been accomplished in the sterile Mars scenario. So it is not evolution that has failed, but lack of a mechanism to convert molecules into life. Why did every potential mechanism fail? Maybe that is not important to consider here. Maybe we should, instead, consider the implications of that failure.

The Solar System has only one body where incontrovertible evidence for life exists. There is a second planet, Mars, where it should be possible for life to exist, if it had got going. But Mars is, and for the purposes of this discussion, always has been, sterile. We can now pursue the debate in one of two directions.

First, the philanthropic argument. Earth is unique. Earth is very special, the 'cradle of life.' We must protect that life, and work in harmony to ensure that life's primary habitat, planet Earth, is not destroyed through over-extraction of minerals, made barren by a combination of deforestation and industrial-scale farming, or propelled into an epoch of global warming by irresponsible increase in CO_2 emissions. All or any one of these scenarios would have grave social, political and economic consequences. This is one set of arguments. There is an alternative viewpoint: Earth is unique. There is nowhere else in the Solar System where life has arisen. So we can harness the resources of other planets to make good the deficits of our own. As terrestrial resources are exhausted, and as population grows, we can look to technological advances to furnish us with other environments in which to live. One possibility, currently only within the realms of science fiction, but not so far beyond the bounds of possibility, is that of terraforming Mars – turning the planet into a second Earth by melting the icecaps to produce an atmosphere that will enable water to be stable at the surface. This may be a flight of fancy. Only time, the friend of evolution, will tell in which direction the human race will move.

Summary/Conclusions

Life is assumed to have evolved on Earth from a unicellular proto-organism, the Last Universal Common Ancestor. The steps from simple molecules to this organism are not fully understood, but there are several proposed mechanisms that can be employed to trace these steps. Life is abundant on Earth, and occupies a range of habitats. Analogous habitats exist on Mars, which have been through all the same processes as Earth, starting from the same planetary building blocks. If life had got going on Mars, there should be some indication of its presence, even if not currently extant. If we find life on Mars, we need an international framework agreement of how to regard that life and its planetary environment, possibly akin to the Antarctic treaty. If, on the other hand, we do not find life (either extant or extinct), then a different set of choices opens up.

This leaves us with the choice between a philanthropic framework for the protection of life on Earth, or a more trenchant case for the exploitation of Mars. Whichever direction is taken, new technologies will require development. Will they cost the Earth?

Coda

As I finished putting together the framework for this essay, the first report of the creation of synthetic life was published (Gibson et al., 2010). Where does such a 'proto-organism' feature in any of our classification schemes or phylogenetic trees? Where, indeed, does it feature in philosophical and ethical considerations of life? Synthetic *biological* life carries us, inexorably, towards synthetic *mechanical* life, robotics, neural networks, and so on. To regard all this as a can of worms brings us, with pleasing symmetry, back to where Charles Darwin both started and ended his career (Darwin, 1881).

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