Astrobiology – A new emerging field of biological sciences

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Recent advances on the origin and evolution of life have greatly developed our understanding of the early stages of life on earth. The claims of signs of extinct life in a meteorite from Mars have prompted much work on how to search for and understand such signs and also address pertinent questions which have baffled man since time immemorial: Where did we come from? Is there life scattered across the solar system or are we truly alone and if so, why? The science, which addresses all these, and many other questions, is the newly coined branch of biological sciences – Astrobiology. It is a science where the general population perceives its own interests being addressed. In this way it also has an ancillary beneficial effect on the public view of science in general. The current article discusses some of these aspects.

ASTROBIOLOGY is the study of the origin, evolution and distribution of life in the universe. There is no agreed definition for Astrobiology and it is a collection and merging of several scientific disciplines. It is a relatively young field, being formed in 1998 at the Ames Research Center, NASA. With recent scientific discoveries and the current tremendous interest in Martian research, the field of Astrobiology has come in the forefront. Complex microbial life on earth arose at least some 700 million years (m.y.) after the formation of the earth 4600 m.y. ago[1–4]. There are clues for microbial existence on Mars, some evidence for a suitable habitat on Europa, and an atmospheric signature has been established by which planets orbiting nearby stars can be searched for signs of presently active life[2,3,5]. Recent advances have greatly developed our understanding of the early stages of life on earth. Molecular biological techniques led to the discovery of a third domain of life, the Archaea. The claim for signs of extinct life in a meteorite from Mars has prompted work on how to search for and understand such signs and search for nanobacteria on earth[6].

How did life begin?

Molecular phylogenetics has indicated that modern-day organisms are descendants of a single-cellular consortium and the occurrence of similar sets of chemical and physical parameters in any astrobiological context would also constitute an opportunity for evolution of ‘life’. Panspermia (also called directed panspermia) is the teaching that life on earth originated from life ‘sperms’, or spores, that arrived from outer space. It is also the name of the theory that life exists and is distributed throughout the universe in the form of germs or spores. Establishing the most likely set of conditions under which life may exist will enhance any search for living organisms. Such a hierarchy is defined as the components of the ‘biological envelope’, a set of environmental parameters that specify the current perception of the outer limits of life. These parameters are derived from microbiological and molecular studies, in particular from the knowledge of extremophile microorganisms[7–9].

Is there life outside the earth?

When we consider searching for life outside the earth, we must consider how such life would differ from that on earth. Our understanding of how life started and evolved is limited, and inferences and interpretations can only be based on examples of life here on earth[2,3]. Thus, while it is conceivable that life could exist in exotic places such as molecular clouds, in interstellar space and be based on a chemical framework other than carbon, C-based organic chemistry seems to be the most potential as the basis of life. A final requirement is environmental stability – little changing conditions that allow the maintenance of life once it is initially established. Where these conditions are, or have been met, the potential for extant or extinct life exists.

Obstacles to life on Mars as it is today

Current biological interest in Mars centres on the prospects that early Martian history conditions may have been suitable for the origin of life[10–13]. In its present state Mars is

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inhospitable to life, at least as we know it on earth. Although Mars may once have been warm and wet, the red planet today is a frozen wasteland. Extreme cold threatens life in several ways: it raises the activation energy needed for metabolic processes, and can lead to the formation of ice crystals within the organism, which damage cells and impede biochemical reactions and the transport of metabolites[14]. Beyond low temperature is the low pressure of Martian atmosphere, about 1% that of the earth[15,16]. At such low pressure, liquids boil at much lower temperatures, and despite the relative coldness of Mars, animal blood would boil at such low pressure. In addition, low pressure can hamper efficient DNA repair. Water is another necessary component for life; without it, dehydration and subsequent DNA damage and death would occur[14]. There may be significantly less nitrogen on the surface of Mars than there is on earth[14] and being the main elemental building blocks of life, there would be a potential problem in bringing life to Mars. Its likelihood and effects have not been fully explored yet, nor have solutions been proposed to overcome a lack of nitrogen, should it exist.

Antarctic: a comparable model for Mars

To assess the biological potential of each of the epochs of Mars, a comparison with that of the McMurdo Dry Valleys of the Antarctic is made under similar climatic conditions. The Martian communities were probably anaerobic in nature unlike the aerobic communities considered in Antarctic studies. On earth, the best analogues of such habitats are the ice-covered lakes of the McMurdo Dry Valleys, Antarctica[17,18].

The notion that the Antarctic cold desert (Ross Desert) can serve as a terrestrial model for Mars is not new, but dates back to the planning of biological experiments for the Viking mission[19] following which this has become a subject of intensive research effort. Cryptoendolithic organisms of the Ross Desert exist under conditions that are far below their physiological optima and on the edge of their physiological tolerance and may often result in fossilization[20–22]; but preservation of such near-surface fossils on Mars is a distinct possibility. Among the universal cyanobacterial communities in the endolithic rocks of Ross Desert was *Chroococcidiopsis*, one of the most primitive cyanobacteria known[6].

Prospects of terraformation and greening of the red planet – reality or a dream

Mars is covered by a layer of ground up rock and fine dust known as regolith. To convert regolith into soil, it will be necessary to add organic matter. On earth, microorganisms play an important role in breaking down dead plants, recycling their nutrients back into the soil, so that living plants can reuse them. But on Mars there is no vegetation to decay, so the dead microorganisms themselves will provide the organic matter needed to build the soil. Thus to form an earth-like ecosystem, one would first need to begin with single-celled microbes to pave the way for future organisms and ecosystem[23].

Among these extremophiles, *Chroococcidiopsis* might be most suitable for the task, for it is one of the most primitive cyanobacteria with the ability to survive in such environments. For clues on how to farm *Chroococcidiopsis* on Mars[6], one needs to look into its growth habitats in the arid regions on earth. But before *Chroococcidiopsis* can be farmed on Mars, the planet would have to be warmed up to just below freezing point[24]. Dead *Chroococcidiopsis* and bacteria could invest the regolith with organic nutrients to form the soil, and the cyanobacteria easily give up dominance to more complex forms of life. This would make it an ideal transitory organism for a new ecosystem on Mars. However, the *Chroococcidiopsis* is still unable to survive in the current cold temperature extremes of Mars[24]. This does not rule out its use. This and other bacteria could be artificially adapted to the Martian environment. The organisms could be grown in simulated Mars conditions to artificially induce a genetic selection process – to breed microbes best suited to the task[25]. One of the prime candidates for genetic engineering is the bacterium *Deinicoccus radiodurans* that can survive exposure to peroxidases and other oxidizers. This organism is resistant to the harsh conditions in Mars and is a prime candidate for genetic engineering. There is hope that this organism could be used to clean up or detoxify the various toxins present in the Martian regolith. Mars has an average surface temperature of –60°C that has to be brought down roughly to 5°C, also there is a need for an atmosphere to breathe. Right now Mars contains little oxygen, if at all[26]. So the first plants and microorganisms that will grow on Mars need to be able to survive without oxygen. The conditions of Antarctica offer the best model to test such plants and microorganisms that can live under the current conditions of Mars. Imre Friedmann discovered lichens and algae living a few millimetres below the surface that could endure the early stages of Mars transformation when the planet would be still very cold[7]. This would require heating up the entire planet by 65°C. This appears to be an incredible task, but planetary scientists propose to go ahead with the plan of manufacturing and releasing large quantities of greenhouse gases on Mars. This would trap light from the sun in the Martian atmosphere and heat up the surface to an average of 0°C and beyond through the process of global warming[27]. As the greenhouse gases raise the average temperature to –20°C, CO_2 ice at the poles and in the soil would sublime from solid to gas and increase atmosphere pressure. Being a greenhouse gas, it will also help in increasing global warming; When the temperature reaches 0°C, large amount of water ice at the poles and aquifers would melt establishing a hydrological cycle and releasing water as gas into the atmosphere. Finally, microbes like *Chroococcidiopsis* and other genetically engineered ones could be released into Mars[25], to establish a biosphere and produce O_2. As the red planet gets warmer during the terraforming process, more plants could be introduced to this new environment. The plants would generate oxygen, and eventually insects, worms and other simple animals that can tolerate high concentrations of CO_2 could be established. After the man-made ecosystem has fully developed, humans would be able to colonize there. For this, fifty years is the time bar. Once the microbes are released, they will begin to change the regolith allowing lichens and mosses to grow around 25 years later. After 25 further years flowering plants would grow[14].

How to recognize the signatures of life on the other world?

Life signatures may be of various types and for *in situ* analysis, simple molecular signatures (presence of O_2, CH_4 or organic material) may be indicative of biological origins. More complex structural signatures (Raman spectra or of key biochemical structures such as chlorophyll) are most reliable. Functional signatures are most varied and carry high levels of confidence. The release of radiolabelled CO_2 from ^{14}C-glucose, detection of ATP by luminometry and generation of an oligonucleotide signal using universal 16S PCR primers are examples. Very high levels of sensitivity have been achieved in biological detection systems based on the activity of known catalytic (enzyme) systems, which include fluorigenic detection and developments in spectroscopic technologies that are aimed at single molecule detection.

Future directions: The challenge of the genome

The determination of whole genome sequences, even those of unculturable organisms, may be a significant step towards an understanding of the total metabolism of a cell and how it can be regulated and adapted to meet environmental changes and pressures. This may be the way forward in understanding the evolution of metabolism, but confusion will probably precede understanding. Already, genes are being uncovered for which no enzymic activity can be detected in the cell, nor for which was any expected as in the Archea.

No doubt, many more surprises will come to light as the analysis of genomes and their protein products advances, and our understanding of the last common ancestor will eventually become clearer and more certain. This still leaves an enormous gap between these organisms and the first metabolically active cells. Simulations and speculations are both stimulating and thought-provoking, but the nature of primitive metabolism before the last common ancestor, or what we might expect to find in extra-terrestrial life forms, remains a largely unexplored question. The field is wide open, but the path to take is unclear[28].

Conclusion

Astrobiology is an emerging field of science and therefore, has an impact far beyond its own boundaries. As a subject, it is unique in being of universal interest and speculation in the non-scientific communities too. The essence of Astrobiology is cooperation and sharing of knowledge between previously independent fields. Astrobiology also looks at the place of life in the universe. It asks important questions like: Was life formation on earth a fluke? Could life on earth have been seeded from outer space? Why is there no life on Mars? Or is there life? Is there life scattered across the universe, or are we truly alone, if we are, why? While we are yet to seek answers to many of these questions, Astrobiology appeals to humanity as a popular field probing into the deepest desires of humanity – where did we come from? Astrobiology is a science where the general population perceives its own interests being addressed. It, therefore, has an ancillary beneficial effect on the public views of science in general. The future contributions to industry and development from astrobiological research are huge. At early stages of development but with great future potential are the applications in biological and biotechnological systems. The benefits to science and industry accruing from the discovery of alternate biologies are beyond the scope of imagination.

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