# Astrobiology can help space science, education and the economy

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ABSTRACT

Astrobiology is a subject dedicated to understanding the origin, evolution and distribution of life. Astrobiology is a multidisciplinary subject within which useful information comes from a variety of environments and from a myriad of techniques. The challenges of the Global Exploration Roadmap contain intrinsic astrobiology questions and opportunities. The potential astrobiology returns include scientific, educational and economic benefits.

MAIN TEXT

The Global Exploration Roadmap (GER) presents a strategy to explore the solar system using both robots and humans in an internationally coordinated fashion [1]. Moving out from the Earth, this exploratory venture begins with the International Space Station, continues through the Moon, the near-Earth asteroids and concludes with our neighbouring planet Mars (Table 1). The progressive exploration of the solar system leads us to encounters with various environments that have relevance to astrobiology (e.g. [2]), a discipline that examines the origin, evolution and distribution of life.

Table 1. Astrobiology and the Global Exploration Roadmap

| Activity | Timing | Targets | Astrobiology related research |
|---|---|---|---|
| Preparation activities | Late 1990s to Late 2010s | Earth & International Space Station | Analogues, microgravity studies |
| Robotic exploration | Early 2010s to Late 2020s | Moon, Asteroids & Mars | Habitability, prebiotic chemistry, potential life detection |
| Human exploration | Late 2010s to Late 2030s | Moon, Asteroids & Mars | Definitive life detection, resource exploitation, colonization |

Perhaps the underlying principle of astrobiology is the supply of life's raw materials. Life on Earth relies mainly on four elements: hydrogen, oxygen, carbon and nitrogen, with smaller

amounts of two other elements, sulfur and phosphorus. The GER will allow the study of the distribution and chemistry of these biogenic elements in our cosmic neighbourhood. The outer solar system is rich in the biogenic elements whilst the life-bearing inner solar system is relatively poor in the same materials. Plausible theories suggest the transfer of material between the inner and outer solar system prior to life's origin [3], and exploration targets identified by the GER allow further study of these concepts.

Once the biogeneic elements are in place, conditions must be conducive to organic chemical evolution and life's origin. The concept of an environment possessing the ability to produce and sustain life is called habitability. Water is key to habitability because it makes up the majority of living tissues. Water must be present in liquid form to sustain the relevant prebiotic and biotic reactions and an extended duration during which water remains in a liquid state is thought to be essential to allow life to originate and evolve. Energy sources must also be present [4]. Chemical energy involves the transfer of electrons between juxtaposed oxidised and reduced materials and the presence of energy sources can be recognised by studying the inorganic and organic chemistry of extraterrestrial environments that would be studied during implementation of the GER.

Planetary surfaces encompassed by the GER provide records of habitability. Our own Earth continues to provide a favourable environment to the present day but obviously habitable conditions elsewhere have been more short-lived. Early Earth and Mars shared similar conditions but the later loss of the majority of the martian atmosphere and hydrosphere represented a divergence in habitability for the two worlds [5]. Comparisons between Earth and Mars can provide evidence on the tempo of life's origin and its persistence and adaptability under changing conditions.

At some point organic chemistry must have transitioned to biochemistry. Earth's rock cycle has obliterated records of the transition from prebiotic to biotic processes. Yet other destinations in the GER may present records of this important step. Pre-life chemistry is present in asteroids that represent an arrested development in chemical steps prior to life [6]. Moreover, the delivery of organic matter by asteroids or comets may have furnished early planetary surfaces with the necessary raw materials for incipient life [3]. Mars has no plate tectonics and its rock record contains many ancient materials [5]. In these early rocks the chemical transition to life may still be preserved. The Moon is ancient and its surfaces very

old, so may act as a relatively passive recorder of chemistry on other worlds as near surface fragments are ejected and transferred through the solar system by impact events [7].

Once life has arisen it begins to alter its environment and shed organic materials during successive life cycles. The effects or remains of life represent biosignatures that can interpreted as fingerprints of past life. Biosignatures are most robust when encapsulated in some form or matrix and certain types are more effective than others for preserving biosignatures. There will be a range of materials encountered during GER activities with different abilities to preserve biosignatures over long periods of time. For example, frozen water and salts are susceptible to temperature variations owing to climate change while clay-rich rocks and silica deposits are affected only by high degrees of metamorphism [8].

Not all astrobiology work that would be facilitated by the GER need take place in environments outside the Earth. The characterization of analogue materials and settings on Earth provide almost unlimited opportunities to hone the capability of techniques and instruments destined for use in space. Well characterised material analogues [9] of the Moon [10] and Mars [11] have provided valuable service to the space community and new analogues of other GER targets continue to be developed [12]. In addition to material analogues, analogue environments [13] also provide valuable opportunities to test. The study of analogue environments and their organisms generates background knowledge that can inform mission design and produce a scientific focus when presented with the multitude of targets available for study on solar system bodies and planets.

During astrobiology studies of extraterrestrial environments one approach is to attempt to recreate the activities of a field geologist by scanning the environment, selecting the most interesting exposures and performing close up analysis of any layers that show signs of fossil life (Table 2). The field geologist approach can be mimicked during a coordinated series space missions where the scanning step is recreated using orbital space craft, the selection of exposures by cameras onboard rovers and the close up analysis by contact instruments (e.g. [14]). The ultimate mimicry of the field geologist is achieved by sample return missions that return materials to Earth laboratories where the most advanced instrumentation can be brought to bear on samples of greatest potential interest from asteroids [15], the Moon [16] and Mars [14].

Table 2. Human robotic relationships and the field geologist analogy. Numbers of samples are expressed as orders of magnitude and are based on the experience of the Mars Exploration Rover Spirit (after [14]).

| Activity | Number of samples | Field geologist | In situ mission | Sample return mission |
|---|---|---|---|---|
| Observation | $1 \times 10^6$ | Field survey | Satellite observation and landing site selection | Satellite observation and landing site selection |
| Selection | $1 \times 10^2$ | Examination of key beds | On-board camera and remote spectroscopy | On-board camera and remote spectroscopy |
| Measurement | $1 \times 10^1$ | Laboratory analyses | Contact instruments and on-board laboratory | Contact instruments and multiple Earth based instruments |
| Interpretation | | Data analysis | Earth based interpretation of Mars data | Integration of Mars and Earth based data |

Meeting astrobiology targets presented by the GER can deliver economic benefits. Attempts have been made to quantify the economic impact of space activities and although the economic results are heterogeneously distributed the benefits can be substantial [17] [18]. Astrobiology is a multidisciplinary subject with many areas of expertise being brought to bear on the understanding of life's emergence, evolution and detection. The problems of small sample sizes and trace organic detection promotes innovation. The challenge is increased for in situ measurements with limited mass, volume, power and reagent resources.

Astrobiology-focused space missions have already generated methods that can be applied to industry. For instance, new techniques for the extraction and manipulation of the fossil organic residues of life lend themselves to issues faced by the petroleum industry and the steam assisted recovery of heavy oil [19] and accelerated recycling of the associated produced water [20] are two such potential applications. The study of terrestrial extremophiles that may reflect alien biochemistries on harsh world's such as Mars provide access to adaptive biochemistries. Extremophiles utilize enzymes, termed "extremozymes", that work under specific conditions [21] and can be exploited by industry. Acidophile enzymes can work in stomachs, alkiliphile enzymes can work in detergents and halophile enzymes can help in the recovery of oil.

Space exploration activities attract enormous public interest and influence the career choices for young people. There is great inspirational value in space exploration and such activities have been suggested to invoke "… a sense of pride, a stirring of the spirit, an opportunity for

vicarious wandering, wondering, or entertainment … a means of attracting young people to study science or engineering" [22]. The correlation of science and engineering graduate students with the NASA budget is evidence of such a link [23].In particular, astrobiology provides a particular stimulus for human curiosity being directed at the subject of alien life. The field of astrobiology flourished in the 1990s accelerated by enthusiasm associated with the suggested detection of life in the martian meteorite ALH A84001 [24]. Immediately scientists crossed the standard community boundaries to meet the new challenges of life detection. Today the search for life outside the Earth represents a fundamental and currently unmet scientific goal. The detection of alien life will have consequences far exceeding those of the "Earthrise" photograph taken during the Apollo 8 mission that captured all of humanity and its environment within a single image. The recognition of our blue water-rich Earth as a capsule for life with a shared origin in the context of a Cosmos with other geneses would have dramatic and irreversible consequences on the human psyche. The GER provides a mechanism by which this potential greater awareness can be achieved.

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