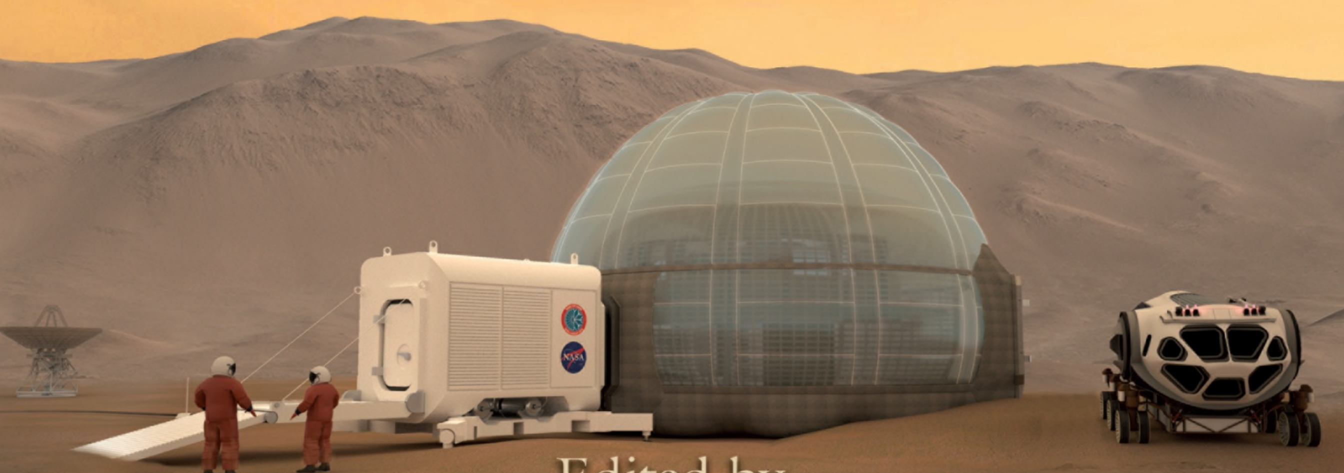
Astrobiology Perspectives on Life of the Universe

TERRAFORMING MARS



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Terraforming Mars

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Astrobiology Perspectives on Life of the Universe

Series Editors: Richard Gordon and Joseph Seckbach

In his 1687 book *Principia*, Isaac Newton showed how a body launched atop a tall mountain parallel to the ground would circle the Earth. Many of us are old enough to have witnessed the realization of this dream in the launch of Sputnik in 1957. Since then our ability to enter, view and understand the Universe has increased dramatically. A great race is on to discover real extraterrestrial life, and to understand our origins, whether on Earth or elsewhere. We take part of the title for this new series of books from the pioneering thoughts of Svante Arrhenius, who reviewed this quest in his 1909 book ***The Life of the Universe as Conceived by Man from the*** *Earliest Ages to the Present Time.* The volumes in ***Astrobiology Perspectives on Life of the Universe*** will each delve into an aspect of this adventure, with chapters by those who are involved in it, as well as careful observers and assessors of our progress. Guest editors are invited from time to time, and all chapters are peer-reviewed.

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Terraforming Mars

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Contents

Preface

“I would like to die on Mars, just not on impact”. Elon Musk

In February 2021 three spacecraft, from three different space agencies arrived at Mars. Two of these, the United Arab Emirates *Hope*, and China’s *Tianwen-1*, joined a host of other space platforms already in Mars orbits, while the third, NASA’s *Perseverance* Rover, proceeded to land safely in Jezero crater upon the Martian surface. This unprecedented international success story has been long in the making, but it marks a distinct acceleration in humanities effort to explore planet Mars. These three spacecraft and associated landers, along with their previously arrived orbital comrades, will deep search the Martian atmosphere, analyse weather cycles and dust clouds, photograph and probe surface topology and composition, as well as look for signs of past, and possible present-day, life. To say that Mars exploration is flourishing seems like an understatement. Indeed, while Mars has been the object of human imaginative exploration for centuries, it is only a little more than a half-century ago that the first fleeting glimpses of its actual surface were revealed by the Mariner 4 spacecraft flyby. Since that time, and the return of those first grainy images, the Martian surface has been mapped and measured in incredible detail - we know the Martian landscape almost as well as we known that of the Earth’s. For all this, Mars is still mysterious and remote - the first human being has yet to plant the first, epoch-changing, foot-print into its red-coloured soil. This remoteness, however, is surely due to change within the next half-century. Humans will walk on Mars, and they will eventually live and die there in large communities housed within vast, above and underground, settlements. Concomitant to, and in parallel with the establishment of the first settlements industry will follow - the early settlers of Mars will have to earn, and justify their upkeep. Exactly how all this industrialization and settlement will proceed is entirely unclear at the present time, which is not to say that much research and hyperbole hasn’t been published. Settlement will happen, but in what manner and when is something that our future-gaze can but dimly see. Like some pointillist picture the greater vista of Mars’s future seems clear but it grows more indistinct the closer the inspection proceeds. For all this, we are on the cusp of change, and Mars patiently awaits its first human visitors. Furthermore, somewhere along the deeper future timeline, when all the hoopla of first landings, settlement construction, and city development is the fodder of stayed news stories, set on the obscure back pages of the *Vancouver Sun* newspaper, a new epoch of even greater revolution might possibly unfold. At some future time, set perhaps within the next century, it may be deemed desirable to terraform Mars. The question is not so much can Mars be transformed, the technology to achieve this goal largely exists today, but why and for whom. Currently it is these latter issues that require much greater thought and consideration - let us not repeat the many colonialist disasters and environmental failures long-wrought by humanity against the Earth on Mars. The path leading to the successful and meaningful transformation of Mars will be a narrow and difficult one to tread, but the potential benefits of making its surface better-suited to human activity and physiology, even if it is never made fully Earth-like, may well prove irresistible to the future citizens of the planet.

The future always holds great promise - provided, that is, we are wise enough to reach-out and embrace its potential offerings. Humanity's journey to the red planet is, as yet, in its early stages, but for all this, plans and possibilities abound. Many innovative ideas of how we might directly explore, first settle, manage surface resources, and even begin to terraform Mars's atmosphere are described within the chapters collected in this volume. Here, under six broad headings, you will find reviews concerning the engineering of vast landscapes, the ethical considerations pertaining to such transformational engineering, the search for indigenous life on Mars, the housing requirements for living on Mars, the mining and processing of *in-situ* mineral resources, and the processes by which Mars might eventually be terraformed. The issues are complex, manyfold, and multi-disciplinary, and it will require the unprecedented cooperation between nations on Earth to bring about the changes envisioned. Of one thing we can be sure, however, there is no shortage of human imagination, ingenuity, ability, and courage. We are collectively up to the challenge, if called to do so, and Mars beckons.

Martin Beech
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September 2021

Part 1

INTRODUCTION

1

Terraforming and Colonizing Mars

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Abstract
Humankind is on the verge of becoming a multiplanet species, but the main obstacle it has to face in this endeavour is that the environment of all celestial bodies in the solar system is very harsh, completely unsuitable for terrestrial-type (and hence, human) life. To colonize the planets, moons and asteroids of the solar system we must create artificial and enclosed environments, where we can live in shirt sleeves conditions. If on one side we are used to live in artificial environments since the neolithic revolution, in particular in some particularly harsh parts of our own planet, it is true that the colonization of the solar system could be made easier only if we start terraforming the places we aim to live in.

For many reasons, the first candidate of this terraforming effort is Mars, since the closest places (the Moon and Venus) are even worse. Terraforming Mars is a huge enterprise, which will take possibly hundreds years and very high costs. The essential aspects of this endeavour, scientific-technological, economical and ethical, are here discussed. In particular, an ethical problem is related to the possibility of existence of indigenous life: if on Mars there are indigenous living beings, most likely at the bacterial level, any effort aimed to terraform the planet likely would cause their extinction. Before any terraforming endeavour is started, a deep study aimed to exclude their existence must be undertaken.

***Keywords*:** Mars terraforming, Mars colonization, greenhouse gases, multiplanet species, extraterrestrial life, planetary contamination, planetary atmospheres

1.1 Introduction

The human species has always experienced an urge to explore and to settle new territories. On Earth, it evolved in a small area in East Africa and from that beginning it expanded on much of the planet, at least in regions which could be easily reached just by walking on land.

It is likely that most of the individuals who participated in this process were completely unaware of it: a band of humans moving its camp by just 10 m each year (always in the same direction) would find itself 10,000 km from its original place in one million years.

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However, things were not as easy as this: in many regions the climate was too harsh for humans to survive, and above all the climate in the various regions of our planet was changing continuously, with terribly cold ice ages and hot interglacial periods, and a continuous alternance of dry and wet periods.

To go through all this humans had to develop specific technologies, and also to adapt themselves with continuous evolutionary changes [1.11]. While the first process was quick enough to allow survival in a continuously changing environment, the latter were too slow and likely played a small role, to the point that in the last few hundred thousands years a single species, *Homo Sapiens*, emerged.

Homo Sapiens developed technologies which allowed to survive in the most harsh climates, particularly in cold climates, which are most difficult for a species developed in the hot African plains. It was observed that the wooden goggles that Inuit wear since the palaeolithic to prevent snow blindness and the multilayer skin garments they use in the open, and without which life would be impossible in these conditions, are as complex as the visor of a space helmet or the space suit we have to wear to explore space.

Apart from the technologies humans had to develop to survive in environments which were very different from those to which they were naturally adapted, later on in their expansion on the planet they had to develop transportation means which were essential for reaching, exploring and colonizing new lands. The most impressive examples are the boats and the navigation techniques developed in Neolithic times by Polynesians, which allowed them to settle practically all the islands of the Pacific Ocean, and the ships that at the turn between the Middle Ages and the Modern Age allowed the era of the geographic discoveries [1.4], [1.5].

Today humankind is at the beginning of a new era of exploration and colonization, and again it must develop enabling technologies to pursue its goals. From one side, the complexity of this new endeavour is unheard of, since, at least in the solar system, the environments in which the new human settlements will be located are much harsher than any environment of our planet, but from the other modern scientific technology, as opposed to the ancient technology based on trial-and-error attempts, is such a powerful tool that we can be reasonably sure that we have all the required means to succeed [1.11].

The point is thus not whether the human species, which developed on Earth, will be able to explore and colonize the nearby celestial bodies, transforming itself into a spacefaring, or multiplanet, species, but when this process will start (Figure 1.1).

1.2 Earth: A Terraformed Planet

Before starting considering these topics, particularly in the view of speaking of terraforming, i.e. modifying the surface and the atmosphere of a planet to make it suitable to human life, we must however go back in time to make some considerations about our own planet.

Our planet is roughly 4.5 billion years old. In the first half a billion years, the whole solar system was undergoing its process of formation, with continuous collisions of planetesimals and red-hot nuclei of planets which were forming. Then everything slowly settled out and our Earth cooled down, developing a solid surface, covered (completely or partially) by an ocean filled with the water carried here by innumerable comets. If we could land on our

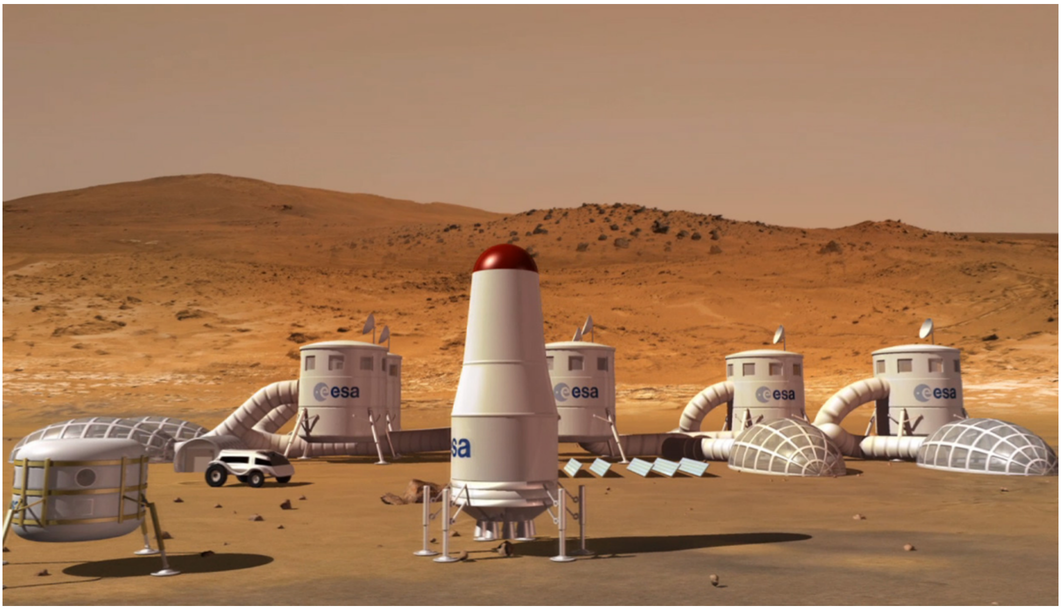

Figure 1.1 Mars Base. Design by Martin Kornmesser and image courtesy of ESA.

planet at that time we would find a planet completely unsuitable for human (and in general animal) life [1.9], [1.18].

The atmosphere of our planet would have been unbreathable, being composed by nitrogen and carbon dioxide, with no oxygen at all.

It was at that time, roughly 3.7 billion years ago, that the first life appeared, most likely in the oceans. And life started evolving in those conditions. The archeobacteria, and the other forms of life which followed, started using the huge amounts of carbon dioxide present in the atmosphere, producing oxygen. This slowly changed the composition of the planetary atmosphere making it suitable for supporting forms of life breathing oxygen, including human beings (Figure 1.2).

We can thus say that the first planet to be terraformed was Earth itself, and the actors of this transformation were the primitive forms of life like unicellular algae, which started the

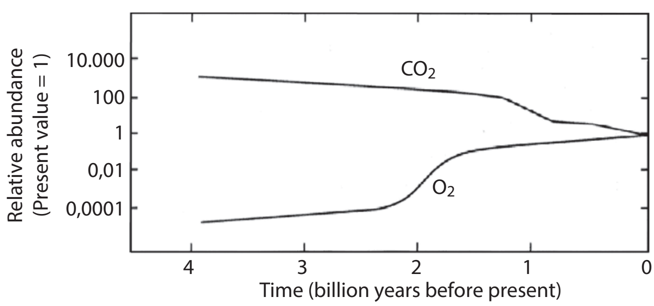

Figure 1.2 Relative abundance of CO_2 and O_2 (relative to the present one) as a function of time. Note the logarithmic scale [1.12], [1.13].

process, and then, in half a billion years, the plants which developed in the ocean to migrate later on dry land, which gave the finishing touch.

During most of this process, the planet had the aspect of a lifeless word – all life was concentrated in the oceans – and the only sign that Earth was a living planet was the presence of oxygen in its atmosphere.

This consideration, developed for Earth, holds for any planet and bear three important consequences.

- The only planets having an atmosphere which is breathable for humans and other animals are planets on which life – or better, Earth-like life – developed to become a very widespread phenomenon, so widespread that it changed completely the initial characteristics of the planet. Moreover, to have a breathable atmosphere, a planet must still have life: if for any reason life disappears from the planet, owing to the high reactivity of oxygen, sooner or later the atmosphere would revert to its pristine conditions.
- The presence of oxygen in the atmosphere of a planet is a marker for the presence of (Earth-like) life.
- During the process of formation of a breathable atmosphere the anaerobic lifeforms of a planet are substituted by aerobic lifeforms, i.e., the living beings which are the actors of this change are very likely to get extinct, or at least to become a marginal part of the biosphere of the planet.

1.3 Planetary Environments

The idea that the planets of the solar system – and also what now we call extrasolar planets, as soon as it was realized that the stars are other suns and likely they have planets – host forms of life is very old, dating back to Greek natural philosophy. Most seventeenth century scientists were of this opinion, even if Galileo Galilei warned that if extraterrestrial bodies are inhabited, the beings living there must be not only different from those we meet on Earth, but even different from what our wildest imagination can predict [1.7], [1.9].

Following this line of thought it was a common opinion that the environments we could find, once we will be able to reach the planets, would be more or less comfortable, but at any rate would allow us to live there.

In the solar system the two closest planets, Mars and Venus, were thought to be habitable. Mars was assumed to be a cold desert, owing to the fact that it is more far from the Sun than Earth, while Venus was thought to be covered by hot and wet jungles, with huge insects, owing to its proximity to the Sun.

In the second half of the 19th century three great astronomers – the Italian Giovanni Schiaparelli, the French Camille Flammarion, and the American Percival Lowell – contributed much to the scientific knowledge of Mars and to its myth. The former drew a number of maps, which remained the best maps of Mars until the first pictures of the planet were taken by space probes. In a number of popular science articles he set his imagination free, proposing that the dark lines, they thought to identify on the surface of the planet, were in fact areas dense with vegetation that flanked artificial waterways, presumably built by an ancient civilization in an attempt to survive the desertification of the planet by bringing water from the melting polar caps to the more temperate and equatorial zones. Consequently, the idea that intelligent beings, or at least complex living beings (similar to Earth's plants and animals) lived on Mars came to be generally accepted, not only in science fiction but also in serious astronomical studies and in the early plans for human missions to the planet [1.10], [1.17].

Even if in the first half of the 20th century some of the classic misunderstandings on Mars were clarified—there was neither oxygen nor water vapor in Mars' atmosphere, very little liquid water, if any, could exist on the surface, the canals were an optical illusion (artifacts of the low-resolution telescopes), and so forth — the general picture outlined by Schiapparelli and Lowell persisted. In the general understanding of the time, Mars was a barren world with a very thin atmosphere, but it was nonetheless habitable, at least by primitive forms of life. If intelligent beings were living there, they would have had to seek refuge underground, perhaps aided by those fanciful atmospheric machines that were depicted in the many fictional descriptions of the time.

In 1960, only three years after the launch of Sputnik 1, Russia (then Soviet Union) launched the first two probes to Mars. Both failed, however, as did the three subsequent attempts launched in 1962 and another in 1964. In 1964, the Americans tried their hand at a Martian probe, launching Mariner 3 and Mariner 4, also intended to do flybys of the planet. The first failed, but Mariner 4 reached Mars on January 14, 1965, and sent back 22 photos. Even if they depicted only 1% of the surface of the planet, these images forever changed mankind's conceptions of the Red Planet. It turned out that the surface of Mars was very similar to that of the moon: it was covered with craters and utterly dry, with no vegetation, no rivers, no lakes. Some of the craters seemed to have some traces of ice, but nothing else. The instruments also revealed that Mars had no magnetic field, meaning there was nothing standing between its surface and the bombardment of cosmic radiation. In addition, the atmosphere, composed of carbon dioxide, had a much lower pressure than previously thought. Not only people could not breathe the Martian air, just going outdoors would require a full spacesuit, only slightly less demanding than that required in interplanetary space. The following probes substantially confirmed these conditions. Even if Mars proved to be much more complex than shown by the first pictures and was not a dead world like the Moon, it was certainly not the planet of Schiapparelli's and Lowell's imaginations.

The Mars of the nineteenth century astronomers was substituted by the Mars of the probes.

A similar fate awaited Venus: the probes which reached the planet and then the few which landed on it showed that the situation on its surface was even worse: it was a hot hell, with a very high atmospheric pressure (almost 100 times that on Earth). Venus air was made mostly by carbon dioxide (96%) and the rest nitrogen and trace gases.

While the probes sent to Venus and Mars sent back these discouraging results, the first human missions to another world, the *Apollo* missions to the Moon, showed that exploration of an airless world with low gravity was possible and humans could walk wearing a space suit and even travel on the surface using a fairly conventional car.

At this point it was clear that the colonization of any world in the solar system involved creating artificial environments completely separated from the planetary environment and using space suits when outdoors.

Thinking about it, this is not a very severe limitation: even on Earth humans do something similar in many instances. All modern commercial airliners have a pressurized fuselage to protect the passengers from the low pressure and temperature of the air outside, which are not much better than those we must endure on the Mars surface. People going around, eating and enjoying themselves in an air conditioned shopping center located in any city in very hot or cold countries, do not live in a less artificial environment than future Mars colonists living in their pressurized dwellings. These buildings can be transported to the Moon or Mars, just by reinforcing their structures to withstand the pressure difference between the inside and the outside and adding airlocks and other devices. But these are just technicalities, the feeling of living in an environment separated from the outside is similar.

Both on the Moon and on Mars another problem adds to that of the lack of an atmosphere (or to the very thin atmosphere): the lack of a magnetosphere which protects the surface from radiation, both Galactic Cosmic Radiation (GCR) and the radiation from the Sun. This may be even more severe than the lack of atmosphere, since radiation is quite harmful to all forms of terrestrial life, including human life.

One of the most effective measures to protect colonists from radiation of all kind is building the habitat underground, and the two bodies we are speaking about offer an excellent opportunity: they seem to be both rich of lava tubes, long – and particularly large, owing to the low gravity – caves existing in many locations. Since in several points the ceiling of these caves has collapsed, mostly due to meteorite and asteroid impacts, the access to these caves is easy.

Living in lava tubes allows to enjoy an almost radiation-free environment and it is even possible to directly pressurize parts of a lava tube to obtain a pressurized habitat.

However, while on the Moon this is a viable approach to build habitats, on Mars it is questionable. Since there is the possibility that the surface, and above all the underground, of the planet hosts fossil or even existing life, a very reasonable strategy to human exploration is subdividing the surface, and the underground, of the planet in zones of two kinds: *normal zones*, where we are sure that no Martian life exists, and *special zones,* where it may be present. In the zones of the former type human exploration is possible with no particular problems of contamination (forward and backward). The zones of the second type are completely forbidden to humans and may be explored only using robotic devices, complying with strict anti-contamination rules.

This strategy can develop in this way: at the beginning, that is now, all the planet is considered as a *special zone*. Then a sample return mission brings back samples from a certain zone, which are accurately examined in search for life. If no life is found, that zone becomes a *normal zone* and humans can land in that place.

Humans supervise the robotic exploration of the surrounding special zones (Figure 1.3), which are de-rated to *normal zones* as soon as it is proven that they contain no life. Operating in this way, the first places where it will be possible to build habitats will be on the planetary surface, while lava tubes will remain *special zones* for as long as they are demonstrated to be otherwise.