Should Mars be made habitable?

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The 'greening' of Mars was the subject of a recent feasibility study. Apart from the ethical issues, further analysis may provide interesting results.

Of all the planets of the solar system, Earth is the lone body that is both *biocompatible* and *biogenerative*. The latter term has been used in the sense that the geological and environmental features have been maintained long enough for life to originate, diversify and evolve into high levels of biochemical, developmental and morphological complexity. Recent attention has focused on the possibility of whether other planetary bodies can be made habitable. Of these, Mars appears to be the most attractive candidate. Attention to this point was drawn almost twenty years ago[1,2], and the US National Aeronautics and Space Administration (NASA) commissioned a report[3] on the habitability of Mars as early as 1976. In more recent times, the issue of the habitability of Mars has been taken up in a comprehensive manner by Christopher P. McKay of the Space Science Division and Owen B. Toon of the Earth System Science Division of NASA Ames Research Center in California, Robert H. Haynes of the Biology Department of York University in Toronto, Canada, and James F. Kasting of the Geosciences Department of Pennsylvania State University in University Park, USA[4-6].

Ecopoiesis is the term that has been introduced in this connection, denoting the making of a home, or the making of an abode for life, or in a more general sense the fabrication of a self-sustaining ecosystem on a lifeless planet. Two other related terms that have been used are (i) *biopoiesis*[7], which refers to the sustainable replication–transcription–translation (DNA → DNA and DNA → RNA → protein) processes that formed the first stage in the formation of life on Earth; and (ii) *terraformation*, which refers to the directed fabrication of an Earth-like environment on another planet. The question of making Mars habitable is thus addressable in terms of terraforming Mars, or making the planet not only biocompatible but also biogenerative.

That Mars is biocompatible has been argued earlier by McKay[8], who pointed out that its size (radius 3880 km), mass (11% of that of Earth), surface gravity (0.38 *g*), incident solar flux (roughly 43% of the terrestrial value), distance from the Sun (1.52 times as far as Earth), orbital parameters (24-h 39-min solar day and 645-day solar year), surface area (as large as the land area of Earth), the various cationic elements necessary for life, and the possible inventory of volatiles (CO_2, O_2, H_2O, N_2, etc.) are all consistent with a habitable state, and that indeed it might be the only candidate for ecopoiesis in the solar system.

However, the environmental conditions that obtain on the surface of Mars are hostile to all forms of life as we know them, and to even simple organic molecules. Its atmosphere is thin and of low pressure, and largely composed of CO_2 (95%), with small quantities of N_2 (2.5%), argon and trace amounts of water vapour (0.03%), O_2 and ozone (O_3). The mean surface temperature is 213 K, with a diurnal variation of about 100 K. These conditions are not conducive to making Mars a biogenerative planet, i.e. one whose geological and environmental features are sustained long enough in conditions for life to originate, evolve, diversify, develop and flourish as on Earth. However, Mars might have been biogenerative early in its history (2.5 to 4 billion years ago), capable of supporting some anaerobic life forms[9]. In other words, it is entirely possible that Mars supported life of some form earlier and has now become an 'extinguished bioplanet'.

All these factors suggest that Mars needs to be 'prepared' in order for ecopoiesis to occur there. Two major things must be done towards terraforming the planet so that life as we know it can be supported there: (i) warming its surface and releasing liquid water and (ii) chemically preparing its atmosphere. After these feats of *planetary engineering*, some *biological engineering* needs to be done to implant communities of organisms that can proliferate in the Martian environment. These would, in effect, amount to *directed* ecopoiesis, which skips the biopoietic stage of planetary evolution. Such a directed ecopoietic step involves genetically constructing microorganisms or choosing already existing ones that would flourish on a warm, wet and anaerobic Mars.

How can Mars be warmed and to what temperature? A desirable value is a mean surface temperature of around 273 K, which would allow the melting of ice and flow of liquid water on the Martian surface, as it did once earlier in Mars' history as the now dry canals (observed first in 1877 by the Italian astronomer Giovanni Schiaparelli) reveal. The best way to heat the planet would appear to be through the *greenhouse warming* effect, as originally suggested by Pollack *et al.*[10] It also appears that the best way to achieve a warmer Martian climate is to increase the partial pressure of CO_2 in its atmosphere from the present $\sim$6 millibar (1 bar = approx. 1 atmosphere) to an optimal value of 2 bar or so. It is believed that such a thick atmosphere of CO_2 might have existed on Mars some 3.5 billion years ago[9] and that, with the change in its climatic history, the CO_2 has been locked up as the dry ice cap on the south pole of the planet (and a similar wet ice cap of water perhaps at its north pole).

Three ways have been considered for bringing about such a thick CO_2 layer on the Martian surface. The first involves black-body heating by spreading black soot or some such dark powder that would absorb more sunlight. This possibility was discussed as a means to vaporize the Martian polar caps as early as 1980 in a popular book[11]. The second is to warm the poles with giant mirrors[5], while the third involves the introduction of greenhouse gases such as the chlorofluorocarbons (CFCs) in trace amounts into the Martian atmosphere. CFCs absorb in the window region of the thermal infrared spectrum where CO_2 and H_2O do not and thus lead to increased heat absorption[12]. The region of particular interest is 800–1200 cm^{-1}. Some of these greenhouse gases are CF_3Br, CF_3Cl, CF_2Cl_2, C_2F_6 and SF_6, which must be introduced at approximately 10 ppm levels (0.01 mbar) in the Martian atmosphere in order to warm it by about 60°C; this value is based on the estimated warming of about 0.1 K by ppb levels of these gases[13]. On this basis, the amount of these gases needed for the purpose would be 4×10^{10} metric tonnes, which is too much to carry from Earth. However, McKay *et al.*[5] argue that a continuous and steady-state concentration of these CFCs can be maintained on the Martian surface through an *in situ* ultraviolet photochemical cycle involving the ambient amounts of Cl, F, Br, N and O and incident available radiation, and accounting for a photolytic lifetime of about 400 years for these gases.

It is estimated[5] that the energy required for this warming of the Martian surface to mean 273 K, through the 2-bar CO_2 and ppm CFC levels, is 3.7×10^6 J cm^{-2}, equivalent to 8 years of Mars solar energy. This amount of energy corresponds to subliming and warming 2 bar of CO_2, warming a layer of regolith 10 m thick, melting ice to make a layer of water 10 m thick, and evaporating the water into the Martian atmosphere. This would take about 100 years to do, provided 10% of the incident solar radiation on Mars is used for the process. As Haynes and McKay point out[6], one needs to worry about the long-term stability of the CO_2. In the presence of liquid water, this CO_2 could be lost owing to carbonate formation. On Earth, such carbonate from the sediment can be recycled and sent back to the gas phase, through subduction at the tectonic-plate boundary. Mars lacks plane tectonics and thus cannot develop a similar long-term carbon cycle.

An atmosphere of CO_2 is not totally hostile to life; certain forms of algae thrive under pure CO_2 (ref. 14). Biological nitrogen fixation by primitive life forms might also be possible under the very low Martian partial pressure of nitrogen[15]. Specially engineered organisms might be made that could thrive under these conditions and produce oxygen, the presence of which is vital for aerobic habitation of Mars. The present level of O_2 on Mars is thought to be only 800 nmol cm^{-3} of soil. Upon total release, this would give only 0.01 mbar. Water, on the other hand, might be available upon warming the planet, since Mars is known to have ancient oceans, ice sheets and hydrology[16]. As McKay *et al.*[5] state, the limiting step of O_2 production on Mars may not be efficiency of photosynthesis but the necessity of sequestering the organic material in sediments where it is not reoxidized. This requires an active hydrological cycle and deep stable basins. Unless vast amounts of water are liberated, this step may prove to be difficult; thus a human-habitable environment is much more difficult to construct than a plant-habitable one. The absence of plate tectonics in Mars, as mentioned above, inhibits operation of the carbon cycle. In addition, the absence of a UV-protecting ozone shield over the planet poses a real threat to life forms on its surface.

Terraforming Mars thus depends on the establishment of pioneering microbial ecosystems in a warm CO_2 atmosphere. However, it may be difficult to effect the transition from the present cold and dry state into a warm and wet state in which the initial microbial forms can evolve over a period of time. Therefore the first priority for assessing the feasibility of ecopoiesis is to assess the amount, state and location of CO_2 on Mars, and also those of H_2O, N, P, Na, K, S and other elements essential for life. Until this information is available, detailed ideas about the biological phase of ecopoiesis are premature. What, however, encourages such an exercise is the fact that early in its life, Mars seems to have possessed a dense atmosphere and liquid water on its surface[16–18]. Volcanic eruption of Mount Tharsis is thought to have

Ethical issues concerning making Mars habitable

For

1. Ecopoiesis useful and desirable long-term human project
2. Necessary for human colonization of Mars
3. Habitable Mars can serve as a refuge should 'nuclear winter' or similar catastrophes occur
4. Even a feasibility study of ecopoiesis (let alone implementation) could generate sufficient scientific and technical advances and spin-offs
5. New frontier and healthy challenges to human imagination and ingenuity
6. Ecopoiesis research would be of relevance and value to many problems on Earth
7. Project less life-threatening and more useful than arms race, and will bring about international togetherness
8. 'Planetary-engineered' Mars useful for astronauts going there

Against

1. Humans have already spoilt Earth; and now Mars too?
2. Mars could then become a military/economic target for exploitation and create more sociopolitical problems on Earth
3. Insurmountable political/legal problems would arise if one nation starts the project on its own
4. Scarce resources would be diverted away from vital terrestrial problems
5. No significant short- or long-term benefits commensurate with the effort and money entailed
6. Would take far longer than the lifetimes of governments and world economic order
7. Could destroy any already existing Martian biota
8. More desirable to leave Mars alone as it is, for scientific, aesthetic and other reasons
9. Some pathological, 'evil' strains might be generated
10. Religious objections

brought about cataclysmic flooding and release of CO_2 into the Martian atmosphere, and thus a warm, wet climate for an indeterminate period of time[16]. Biopoiesis could thus have occurred on early Mars, only to have been smothered and frozen out by the subsequent arid cooling of the planet. In that event, some organic nutrients such as sugars, amino acids and nucleic-acid bases might still exist buried in the regolith or in the permafrost. With the planetary warming that has been suggested above, these might be released in the Martian waters and could support anaerobic heterotrophic organisms. If a significant quantity of such biomass develops, photoautotrophs and plants could be introduced in UV-protected zones on the Martian surface. Further studies that shed light on the chemical inventory of Mars are necessary for this plan to be considered feasible.

Ethical issues

Ecopoiesis raises several important issues of ethics[4,6,19]. Ethics on Earth have traditionally been both geocentric and anthropocentric. 'Exploitation of nature for the good of man' has been the ethic that has allowed several centuries of industrialization and technology. The recent realization that in this process we have wrought significant ecological damage has led to a shift towards *ecoethics* or environmental *dharma* or the 'tao of life on earth'. Ecopoiesis on Mars extends the dimensions of ethics and poses newer challenges both in its favour and against it.

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