Running head: LIFE FROM LIFELESSNESS

Life From Lifelessness: Ethical, Biological and Technological Issues Relating to Martian Terraforming

James J. Coogan

Embry-Riddle Aeronautical University

October 2006

Abstract

For the past several decades, scientists have worked to develop a plan for terraforming (i.e. making more like Earth) other planetary bodies within our solar system. Mars is one of the best candidates for such planetary engineering, since it is similar to Earth (e.g. water, similar day length, etc.). Theoretical methods for atmospheric regeneration and the introduction of microbial life are seen as the best means to effect Martian terraformation. Debate continues, however, as to whether any such change should be attempted, since the process may destroy existing Mars ecosystems. Further research is required to determine if life exists on Mars and how conditions on the planet may be best adjusted to support some form of life.

Introduction

In the movie *Star Trek II: The Wrath of Khan*, a device designed to transform a lifeless moon into an Earth-like body provides humanity with great potential to alleviate population overcrowding and overcome a lack of natural resources. While initially successful, this "Genesis Device" also comes to be seen as a weapon, capable of destroying existing life and replacing it with new life (Roddenberry & Meyer, 1982). Like so many other futuristic ideas presented in science fiction novels and movies, the concept of planetary engineering continues to intrigue scientists. For several decades, many have attempted to bring Roddenberry's ideas to fruition. If humanity is able to determine how to make a lifeless planet habitable for itself, many possible avenues for Space colonization and exploration may be opened. At the same time, however, ethical dilemmas arise to question whether humans have the right to make such a decision.

The process of transforming a planet or moon to a condition suitable for life is called planetary engineering. Initially, this discipline was defined as the application of technology with the goal of changing the environment of a planet (McKay, 1982). However, many scientists now use the term interchangeably with terraforming, which actually indicates a global transformation (i.e. including gravity, atmosphere and temperature) of a planet or moon to Earth-like conditions (Clement, 2005). Further adding to the confusion, an element of the planetary engineering process called ecopoiesis (i.e. making a planet habitable for bacterial life) has also been used interchangeably with terraforming (Thomas, 1995). The National Aeronautics and Space Administration (NASA) therefore recently redefined terraforming as "the deliberate alteration of an environment or climate on a planetary scale" (National Aeronautics and Space Administration [NASA], 2004, ¶ 4). For this reason, the author considers terraformation as synonymous with planetary engineering.

There are several known planetary bodies that may be considered as candidates for terraformation. Currently, the planets Mars and Venus and the moons Titan and Europa seem to have potential. Venus has the drawback of a slow rotation rate and Titan and Europa are a significant distance from the Sun. As for Mars, the distance from the Sun is not optimal and gravity is only 0.38 of Earth gravity. Still, Mars is a planet with a day-length similar to Earth (24 hours, 37 minutes), a planetary tilt like Earth's (25° 12') and probably has water (Rice, Gustafson & McKay, 2001). This potential allows scientists to seriously consider Mars as the best-known candidate for terraformation.

Discussion

The first efforts for determining Mars' potential for terraforming were made in preparation for the Viking missions in the 1970s. With the successful landing and more than eight months of study by the two landers, much was learned about Mars' planetary chemical constitution (Rummel, 2001). Studies on the existence of life were less conclusive, but further missions like those of Pathfinder in 1997 and the Mars Exploration Rovers, *Spirit* and *Opportunity*, in 2004 confirmed many of the Viking findings on the characteristics of Martian atmosphere, gravity and other conditions (Mars, 2006). The existence of water, in great quantities, trapped in the polar ice caps has led to great excitement among planetary engineers as to the potential for returning Mars to an earlier state (i.e. with an atmosphere and liquid water). One of the most ambitious examinations of Martian potential for life will occur with the Mars Sample Return Lander, scheduled for launch as early as 2014 (NASA, 2006). Each mission provides further knowledge about the Martian capacity to support life. The desire to terraform Mars also increases as scientists gain understanding about its environment.

Ethics

Of course, the first problem that must be faced by planetary engineers is confirmation of the existence or non-existence of life on Mars. Ethical frameworks for dealing with this eventual decision have already been created. McKay first proposed three “normative axioms” for Martian terraformation in 1990. These were anti-humanism and preservation (based on belief that humans are always harmful and should leave Nature alone), stewardship (based on belief that humans should use Nature wisely for humanity’s own benefit) and intrinsic worth (based on intrinsic worth of objects even if they have no use to humans). It is very clear that the initial decision to change the Martian atmosphere will be influenced by these viewpoints (McKay, 1990).

Fogg has further categorized the rival ethical theories which most likely will influence the final decision about whether Mars can be terraformed: anthropocentrism (based on preserving life with moral and rational thought, like people), zoocentrism (based on preserving life with individual consciousness, like animals), ecocentrism (based on preserving any life at all) and preservationism (based on keeping the cosmos the way that it is). Each of these theories will have proponents and opponents, but Fogg believes that a decision about whether to terraform a planet must be made by choosing to value life (Fogg, 1999).

In the Great Terraforming Debate of 2004, several prominent authorities on Martian exploration and colonization and some with ethical concerns about the entire process discussed the dilemma of human use of Martian resources. Included in the NASA sponsored (through their *Astrobiology* magazine) debate were Greg Bear, David Grinspoon, James Kasting, Christopher McKay, Lisa Pratt, Kim Stanley Robinson, John Rummel and Donna Shirley. During the proceedings, it became clear that there is currently a great divide between those who believe that humanity has a right to proceed with Martian terraforming and those who think that humanity has already caused enough damage to the underdeveloped areas of Earth. The possibility for disturbing an established ecosystem was also of great concern to some in the debate (Astrobiology Magazine, 2004).

One last problem in the terraformation discussion is related to the possible introduction of life from Mars into the ecosystem of Earth. In the same way that something seemingly innocuous (e.g. introduction of bacteria to Mars) could have lasting effects, NASA's Mars Sample Return Lander could bring back something from Mars that contaminates Earth. One need only look at examples like the Africanized honey-bee (*Mellifera scutellata*) and nutria (*Myocastor coypus*) that have plagued areas of the world to which they were not native. The Martian sample return could also create an ethical dilemma that should not be overlooked. Rummel proposes a series of questions that should be asked before anything from either environment is transferred. Initially, these relate to testing and minimizing the sample. He then insists that scientists must have an effective protocol to manage potential contamination (Rummel, 2001). Failure to heed his warnings could lead to something completely unforeseen on the Earth surface and make terraformation of Mars seem unimportant for many years to come.

Process

There are several steps that must be taken to ensure that Earth-based life forms could exist on Mars. Planetary engineers plan to recreate a stable atmosphere (including raising the surface temperature and pressure), bring about the release of trapped water and introduce microbes to continue to planetary development. There are several suggestions about how the atmosphere might be reformed over Mars. Each assumes that there is a direct relationship between the temperature, pressure and carbon dioxide levels on the planet. If planetary engineers are able to change the current balance, it is assumed that the other factors would also change, leading to the formation of a new Martian atmosphere.

Orbiting Mirror. A mirror aimed to reflect sunlight on the Martian South-Pole may be sufficient to melt the trapped carbon dioxide in that region. Zubrin and McKay propose that a mirror with a 125-kilometer radius could be placed in a stationary orbit of 214,000 kilometers to cover the entire pole area on the surface of Mars. Such a mirror could be made of aluminized mylar and could be manufactured in Space. It would actually only raise the polar temperature by five (5) degrees Kelvin, but it should be sufficient to initiate release of carbon dioxide. This, in turn, would eventually lead to the development of a stable atmosphere and increase the surface temperature of the rest of Mars (Zubrin & McKay, 1997).

Ammonia Asteroids. Another proposal involves crashing an ammonia asteroid into the Martian surface. While seemingly difficult, some scientists suggest adding propulsion systems to asteroids from the Kuiper Belt, since they move at a slower velocity than other asteroids in the solar system, and steering them into a collision course with Mars. If an ammonia asteroid of at least 10 billion tons hit the planet in this process, it would create a dust cloud over the surface which would then help raise the temperature of the planet by as much as three degrees centigrade. Zubrin and McKay suggest that using 40 such asteroids could double the Martian temperature. However, that many impacts may make Mars uninhabitable for humans. An alternate suggestion involves a theory that there might be a benefit in introducing bacteria to metabolize nitrogen and water to continue development of ammonia (Zubrin & McKay, 1997).

Super Greenhouse Gases. Ironically, one of the proposals for atmospheric creation is to release on Mars the very same greenhouse gases that currently are blamed for global warming on Earth. Gerstell, Francisco, Yung, Boxe and Aaltonee have proposed the release of chlorofluorocarbons (CFCs) to help make Mars habitable. They surveyed 21 fluorine compounds to determine their usefulness in creating an atmospheric barrier to maintain temperature on the Martian surface. Unfortunately, their findings also concluded that CFCs would need to be constantly replenished (nearly 400 kilotons per year) for the effect to continue. Also, there was no evidence that CFCs could actually initiate the warming process independently. The problem of where fluorine would be found was also a problem (Gerstell, Francisco, Yung, Boxe & Aaltonee, 2001). Zubrin and McKay proposed development of factories to ensure production of these greenhouse gases (Zubrin & McKay, 1997).

Ozone-Layer Creation. One issue that could prevent human habitation of Mars is the extreme level of ultraviolet (UV) radiation in the current atmosphere (Budzik, 2000). To counteract this, some have suggested using genetic engineering of known life on Earth to develop naturally UV-resistant plants, insects and animals (Rice et al, 2001). In addition, the creation of a sustainable ozone-layer would be very useful to enhancing the capability of any new Martian atmosphere to protecting life on the surface. Hiscox suggests that one of the priorities of planetary engineers should be to use some of the trapped carbon dioxide to create ozone. This process, called photodissociation, causes carbon dioxide in the upper atmosphere to transform into ozone and carbon monoxide. Greenhouse gases are another vital part of this process (Hiscox, 1996). The creation of even a partial ozone-layer would greatly enhance the survivability of life on Mars.

Microbial Colonization. Another means of terraformation of Mars is the use of bacterial and microbiological organisms. While probably unable to initiate atmospheric change on their own, such Earth-based life forms could serve the process after planetary temperatures begin to rise. These organisms would need to be able to convert carbon dioxide to oxygen and also cycle nitrogen with ammonia. Several organisms, such as the algae *Cyanidium caldarium* (converts CO_2 to O_2) and *Azotobacter* (converts N_2 to ammonia), have been proposed for introduction on Mars (Thomas, 1995). Current research involves simulations using bacteria from the Atacama Desert in Chile, one of the driest environments on Earth (Rice et al, 2001). Since the environment of Mars is currently considered to be very similar to this area, it is assumed that these bacteria may be able to survive there, even under current conditions. The NASA Ames Research Center has developed the Space Hardware Optimization Technology (SHOT) Martian Environment Simulator to test this theory. In 2005, Thomas and a group of researchers determined (from preliminary results) that some of the organisms have potential to survive for at least five weeks (Thomas, Boston, Todd, Boling, Campbell, Gregerson, Holt, McSpadden & McWilliams, 2005).

Nuclear Mining. Without the ability to cause massive impacts with asteroids, humanity may instead be able to use some of its nuclear arsenal to create a radioactive fall-out cloud over the surface of Mars. Fogg has suggested that detonating a nuclear device designed to release trapped carbon dioxide could lead to creation of an atmospheric shield. Once this is completed, the temperature of the planet should increase and there would be a chance for further development of the super greenhouse gases. Unfortunately, this method could also make large areas of the Martian surface uninhabitable for many years (Fogg, 1989). Another, related, suggestion is to use underground detonations of nuclear devices to increase volcanic activity. However, there are so many negative consequences from the use of nuclear explosions that such an idea might only be useful in the absence of any other alternative.

Transitional Solutions

In addition to basic adjustments to the Martian ecosystem, there will be further problems related to the developing conditions on the surface. Even if the process could be completed quickly, there would be an intermediate period that would require transitional solutions.

Controlled Ecological Life Support System. The development of an effective Controlled Ecological Life Support System (CELSS) would be one important part of a successful colonization strategy during the terraformation process. Using a closed loop system, involving minimized interaction with the Martian ecosystem (it would require initial interaction upon construction or deployment), would allow explorers to sustain themselves on the planet Mars without causing irreparable damage. In addition, many of the tests required to determine success for future terraformation could be completed within this biosphere (Clement, 2005).

Greenhouse Simulations. Even if the CELSS were not possible, there would be great incentive for early Martian colonists to use greenhouses to simulate the technology and biological functions listed above. The development of procedures and testing of planetary engineering concepts could provide vital support for future terraformation plans. Hiscox proposes that colonists would actually be a requirement for initial assessment of the Martian surface and for providing a detailed inventory of materials available on the planet (Hiscox, 1996).

Conclusions

It is clear that a great deal of care must be taken as humanity determines what can be done with Mars to make it habitable. Perhaps the greatest question that must be answered (possibly requiring decades of further study) is whether there is actually life on Mars already. At this time, the Mars Sample Return Lander may be the best hope for providing an answer. Despite the potential of this mission to answer decades old questions about the existence of life on Mars, it may take many more years of analysis before scientists on Earth are able to determine the truth. If life is discovered, the governments of the Earth should all have an opportunity to be involved in the decision about whether humans should visit or colonize the planet, proceed with terraforming or leave the planet in its current state. Even if it is determined that large-scale planetary engineering is not morally proper, there are still possibilities for creation of a biosphere on the Martian surface so that humans may explore the planet while living within an Earth-like environment. However, if no life is found on the surface of Mars, terraforming could commence.

But even if scientists are able to begin the terraforming process, planetary engineering on Mars may be delayed or prevented because warming the planet's surface (for the purpose of melting trapped carbon dioxide) might actually be beyond the means and technology of our current society. Even if a nuclear explosion was initiated or an asteroid could be made to impact the Martian surface, the results might prevent human habitation for decades or centuries. Given the extraordinarily large distances (i.e. travel times) to move frozen fluorine bodies within the Martian orbit, it appears unlikely that such a plan is within the grasp of early 21st Century technology. Instead, the orbiting mirror seems to provide the best chance for short-term success. It cannot completely correct the problems that exist within the current Martian environment, but it could initiate a gradual (and even reversible) process, allowing for further atmospheric development over time. Thus, while terraforming in the truest sense (i.e. humans can walk the surface of Mars with no breathing devices or radiation shielding) may not be completed for millennia, a rudimentary form of human colonization might commence much sooner.

Research on bacteria and microbes appears to be providing promising opportunities for post-atmospheric improvement. It seems that introduction of this type of life could be introduced within a very short time after initial atmospheric engineering was completed. Organisms that feed on carbon dioxide, fluorine and nitrogen have been shown to have potential to further enhance the planetary ecosystem before the introduction of further flora and fauna.

Unless the gravitational conditions on the planet can be changed, Mars can never be made completely Earth-like. Despite this, there is a very good chance that Mars will someday be habitable for some form of life. It may not even be classified in the way that humanity knows life today, but planetary engineers definitely have an opportunity to produce life from lifelessness.

Recommendations

As NASA has already planned, both manned and unmanned missions to Mars must continue. Every launch that explores another region of the planet brings humanity a little closer to determining the actual possibilities for making Mars a habitable planet. However, while many may hope that terraforming can transform Mars into an Earth-like environment during the present era, it is more likely to take many lifetimes. In the meantime, the question of life must be considered to be the most important goal of planetary research. No matter what humanity may believe about it’s own importance in the Cosmos, organisms that exist on other planets must be examined and the needs of all life weighed in the decision of Martian colonization. Exploration itself can inadvertently guide the future biological development of a foreign ecosystem (as even the European colonization of the Americas in the 16th Century has shown). Concerns about contamination, both from Earth and from Mars, are valid and should not be taken lightly.

Of the proposals for permanent Martian terraforming, the most promising may be construction of the orbiting mirror. Even before manned missions to Mars, mirrors of small size could be sent into orbit to reflect light on the polar surface. The associated release of small amounts of carbon dioxide could then be directly measured. The larger mirror, designed to completely release trapped polar carbon dioxide, could then be deployed with some idea as to the success of the process. It would be unwise to release too much of the trapped carbon dioxide, however, before tests on the complete viability for these mirrors is known.

Continued use of the SHOT Martian Environment Simulator should provide more conclusive data on bacterial and microbial potential. Once the decision for terraformation of Mars is made, it would be best for the NASA to introduce photosynthetic organisms sent on unmanned probes to specific areas of the planetary surface. If these organisms survive and develop, it may be possible for manned missions to develop a kind of domed habitat (e.g. CELSS) that will allow for such bacteria and other plants to use carbon dioxide in the Martian atmosphere and convert it into breathable oxygen within that biosphere. If air could be circulated in large enough quantities, the domed environment could eventually provide a model for terraforming on a planetary scale. A further plan of action would be to introduce small “fluorine factories” on the surface of Mars. Situated next to the domed environment, these factories could be tested for their success in creating greenhouse gases. Lastly, there could be small amounts of nitrogen (either brought to Mars or mined from the planet) tested with the microbiological organisms that convert nitrogen to ammonia. In this way, all the mechanisms for planetary wide terraforming could be evaluated.

Once humanity has decided on its plan for Mars, the final planetary engineering process would begin. First, the large mirror could be deployed to evaporate the polar carbon dioxide on a massive scale. Perhaps a small explosion, generated on the surface, could facilitate the development of a cloudy atmosphere. Then, larger fluorine factories could be built on Mars to continue production of super greenhouse gases. Lastly, photosynthetic organisms could be employed to continue development of the atmosphere. This entire process could take many decades to occur. Manned missions may need to stay away from the planet (i.e. not live there permanently) during this process. Hopefully, the end result is a complete transformation of the Martian atmosphere. Earth-based life forms, specifically plants, would hopefully allow for a greener planet and for a new cycle of photosynthesis to be established.

References

Astrobiology Magazine. (2004). Great terraforming debate (Parts I through VII). Retrieved September 9, 2006, from http://www.astrobio.net/terraformdebate.html.

Budzik, J. M. (2000, May). *How to terraform Mars: An analysis of ecopoiesis and terraforming research*. Unpublished manuscript, Dartmouth College.

Clement, G. (2005). *Fundamentals of Space Medicine*. Dordrecht (The Netherlands): Springer.

Fogg, M. J. (1989). The creation of an artificial, dense Martian atmosphere: A major obstacle to the terraforming of Mars. *Journal of The British Interplanetary Society*, *42*, 577-582.

Fogg, M. J. (1999). *The ethical dimensions of Space settlement* (Report IAA-99-IAA.7.1.07). International Astronautical Federation and International Academy of Astronautics.

Gerstell, M. F., Francisco, J. S., Yong, Y. L., Boxe, C. & Aaltonee, E. T (2001). Keeping Mars warm with new super greenhouse gases. *Proceedings of the National Academy of Sciences, 98*, 2154-2157.

Hiscox, J. A. (1996). Biology and the planetary engineering of Mars. Retrieved October 7, 2006 from http://spot.colorado.edu/~marscase/cfm/articles/biorev3.html.

Mars. (2006). In *Encyclopaedia Britannica*. Retrieved October 7, 2006, from Encyclopaedia Britannica Online: http://www.britannica.com/eb/article-54246.

McKay, C. P. (1982). Terraforming Mars. *Journal of The British Interplanetary Society*, *35*, 427-433.

McKay, C. P. (1990). Does Mars have rights? An approach to the environmental ethics of planetary engineering. Published in “Moral Expertise” edited by MacNiven, D.

National Aeronautics and Space Administration. (2004, March 25). *NASA presents star-studded Mars debate* (Release 04-22AR). Retrieved September 9, 2006, from http://www.nasa.gov/centers/ames/news/releases/2004/04_22AR_prt.htm.

National Aeronautics and Space Administration. (2006, February 13). NASA's solar system exploration: Missions: By target: Mars: Future: Mars Sample Return Lander. Retrieved October 10, 2006, from http://solarsystem.nasa.gov/missions/profile.cfm?Sort=Target&Target=Mars&MCode=MarsSample.

Rice, E. E., Gustafson R. J. & McKay, C. P. (2001). Terraforming Mars via ISRU (Report AIAA-2001-0936). Report given at the 39th American Institute of Aeronautics and Astronautics Aerospace Sciences Meeting & Exhibit, 8-11 January 2001, Reno, Nevada, and published by the American Institute of Aeronautics and Astronautics.

Roddenberry, G. (Writer/Creator), & Meyer, N. (Director). (1982). Star Trek II: The Wrath of Khan [Motion picture]. United States: Paramount Pictures.

Rummel, J. D. (2001). Planetary exploration in the time of astrobiology: Protecting against biological contamination. *Proceedings of the National Academy of Sciences, 98*, 2128-2131.

Thomas, D. J. (1995). Biological aspects of the ecopoeisis and terraformation of Mars: Current perspectives and research. *Journal of The British Interplanetary Society*, *48*, 415-418.

Thomas, D. J., Boston, P. J., Todd, P., Boling, J., Campbell, K. A., Gregerson, R. G., Holt III, Amon, McSpadden, T. & McWilliams, L. (2005). Early results of ecopoeisis in the SHOT Martian Environment Simulator. Published by the Mars Society: *Proceedings of the 8th International Mars Society Meeting*, Crossman, F. editor.

Zubrin, R. M, & McKay, C. P. (1997). Technological requirements for terraforming Mars. *Journal of The British Interplanetary Society*, *50*, 83-92.