Chapter 18
TERRAFORMING MARS

Livermore’s Lowell Wood addresses the Convention.

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PHYSIOLOGICAL ECOLOGY OF TERRESTRIAL MICROBES ON A TERRAFORMED MARS

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In this paper we will discuss terraforming Mars to make an environment habitable for microbes with processes that can effect change over hundreds of years. Based on currently available evidence, the present climate of Mars is characterized by a number of environmental factors that are so extreme that they preclude colonization by terrestrial microorganisms. What are those extreme environmental factors?

First, Mars is about 1.52x as far from the Sun as Earth. Consequently it receives about 43% as much sunlight. That distance results in a maximum irradiance of 860 µmol quanta.$m^{-2}.s^{-1}$ (PAR) instead of 2000 on Earth (Table 1). That level is not a problem as far as photosynthetic microorgansims are concerned. Most algae and cyanobacteria can do well on far less. The level of UV radiation, however, is serious and lethal for all but a few hardy microbes. UV radiation is one serious limiting factor for terrestrial life on Mars.

Table 1

PHYSICAL PARAMETERS OF MARS

A surface gravity of 0.38 g seems to be adequate for terraforming. Microorganisms are little affected even by zero g in space. The rotation period is 24.6h. Even if this value were much longer (48 to 96h), microbes should still be able to prosper. Since obliquity is close to that of Earth, Mars has seasons, but seasons are less important to microbes than to higher organisms. This group of parameters is suitable for microbial terraforming. The next two are crucial.

The average surface temperature of Mars is very cold at -60°C. Earth by comparison has an average surface temperature of +15°C. The atmospheric pressure on Earth is 1013 mbar at sea level. On Mars this value is only 6-10 mbar. This pressure is so low that liquid water is unstable on the surface. Water exists as gas or ice and behaves much like dry ice does on Earth. Lastly, the composition of the two atmospheres is very different. Earth's is mostly N_2 (78%) and O_2 (21%) while that of Mars is 95% CO_2 with a little N_2, O_2, and H_2O. So here we have three major barriers to life: very low average temperatures, low atmospheric pressure, and essentially no liquid water.

If this were all there is to the story of Mars, there would be little prospect for terraforming it. However, Mariner, Viking and now Surveyor and Pathfinder have provided ample evidence that the past history of Mars was much warmer and wetter. The southern highlands contain many extensive valley systems resembling dried-up river networks (Mars Channel Working Group 1983). Valles Marineris contains mesas that are now interpreted as sediments left by large lakes (Nedell *et al.* 1987). The northern hemisphere contains many outflow channels through which huge floods once surged, leaving islands behind and perhaps filling a vast boreal ocean that left remnants of ancient shorelines (Parker *et al.* 1993).

In order for Mars to have all that water flowing on its surface, it must have had a much warmer, wetter climate and a denser atmosphere in the past. Presumably that atmosphere was mostly CO_2 with N_2 and H_2O in greater amounts. Where did all this atmosphere and water go? If it were lost into space, there would be no possibility of terraforming because all these essential volatiles would be unavailable to restore the past climate. Fortunately, for planetary engineers of the future, it appears that most of that CO_2, N_2 and water are still there. They are just frozen or locked up in the regolith. How do we know (or suspect) this?

Water is a good example. We know a lot of it is still there because we can see evidence of it from space. Both the northern and southern permanent polar ice caps are believed to be mostly water ice (with some dry ice). If we take an inventory of all the water we think is on Mars, we get the data in Table 2. The permanent polar caps contain the equivalent of 1 m of water spread over the entire globe of Mars. The layered terrain (which is an area of alternating layers of dusts and ices around each pole) contains about 3 m more. Polar ice lenses are large areas of water frozen into the regolith like permafrost around each pole down to about 40° of latitude. This source is thought to contain about 23 m of water globally. Minerals and the regolith hold about 13 m more. The last two, ground-ice and groundwater, are crude estimates of large reserves based in part on impact crater morphology. So the water is there.

What about our other volatiles: CO_2 and N_2? Our estimates of these other volatiles are more uncertain (Table 3). If the low estimates are correct, then terraforming would be difficult and impractical. If the middle to high estimates are correct, then terraforming could proceed in a straightforward manner. The best scenario would be to have as much N_2 as possible and less than a 1000 mbar of CO_2. Our knowledge of N_2 is really poor. If Mars outgassed 300 mbar but the present atmosphere has only 0.3 mbar, where is the rest? Is it present in the regolith as nitrate? For now, assume a middle to high volatile inventory on Mars for terraforming.

Table 2

PRESENT LOCATION OF WATER ON MARS

Table 3

ESTIMATES OF MARS VOLATILE INVENTORY

How do we go about terraforming Mars? The two key physical parameters are low average surface temperature and low atmospheric pressure. They are interrelated. Mars is cold because its atmosphere is so thin. Its atmosphere is thin because it is so cold some CO_2 freezes out. The focal point in terraforming is to warm up Mars. If we can raise the average surface temperature, volatiles will enter the atmosphere. A thicker atmosphere holds heat better, raising the surface temperature further. A runaway greenhouse effect could take place and send the planet into a new warmer, stable equilibrium, perhaps with an atmospheric pressure of 90 to 400 mbar CO_2 (Fogg 1995)

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So how do you heat up a planet? One early proposal by James Oberg in his book *New Earths*

(1981) was to place huge solar mirrors in orbit to increase the total solar energy striking the planet. Another proposal originated by Lovelock and Allaby in *The Greening of Mars* (1984) was to introduce greenhouse gases into the Martian atmosphere. Chris McKay, Owen Toon and James Kasting (1991) refined this idea to suggest production of fluorocarbons on Mars from regolith resources. A variety of different compounds, known to be ozone safe, can hold the heat in the atmosphere. Zubrin and McKay (1996) have suggested a synergistic approach: solar mirrors and greenhouse gases. Together the two approaches increase total solar radiation and increase heat retention. As mirrors and gases raise the surface temperature, volatiles enter the atmosphere and pressure rises. Liquid water becomes stable and eventually microorganisms can be introduced.

What then will be the source and form of the first terrestrial microorganisms on Mars? To begin the biological aspects of terraforming, we go to the southern end of the Earth where we find the hardiest organisms in the Dry Valleys of Antarctica. Many dry valleys contain lakes, beneath whose permanent ice cover, bizarre mats of cyanobacteria can be found. The surrounding barren landscape appears lifeless. But the rocks hide their surprises! In crevices and fissures and in the pore spaces between grains beneath their surfaces, these rocks hide a strange community of microorganisms and lichens called cryptoendoliths (hiding inside rocks) (Vincent 1988). These organisms will very likely be among the first implanted on Mars.

How will they respond to the Martian environment early in the terraforming process? Water will be stable on the surface and temperatures will be more moderate, but the atmosphere will be mostly CO_2 and have little O_2. Antarctic and arctic microbes will not be greatly hindered by low Martian temperatures so long as liquid water is available part of the year. A largely CO_2 atmosphere will be favorable to anaerobic microorganisms. But many organisms normally thought of as aerobic can thrive in almost pure CO_2. For example, Seckbach (1970) grew the algae Scenedesmus and Cyanidium in pure CO_2. These eukaryotic cells can produce their own oxygen in the light and switch to anaerobic pathways for energy in the dark (Spruit 1962). Other research has shown that if cyanobacteria and green algae are grown at elevated CO_2, mutants will arise in cultures which require those high CO_2 levels to grow (Spalding *et al.* 1983, Marcus *et al.* 1986). Such research suggests that we may be able to grow microbes under conditions which will select for mutants adapted to Martian terraformed conditions.

As more and more ice melts and enters a hydrological cycle on Mars, pools of water may form on the open surface. Aquatic organisms from Antarctic lakes could then be introduced into them. One major problem remains. We have not mentioned the role high incident UV radiation will play. So long as UV radiation remains high, microorganisms will be confined to underneath or within rocks or under the surfaces of pools of water where they are shielded. Martyn Fogg (1995) estimated that an effective UV radiation screen could be created if 2 mbar of O_2 were manufactured and released into the atmosphere from carbonate rock. If this were done at the same time as the manufacture and release of greenhouse gases, then microorganisms would be able to thrive on exposed surfaces of rocks and regolith.

What about nitrogen? We know there is about 0.3 mbar of N_2 in the atmosphere. We assume there is nitrate in the regolith and hope there might be as much as 300 mbar equivalent there. Nitrogen is essential for microbial growth in amino acids, proteins and nucleic acids. If it is there, how might a nitrogen cycle resume on Mars? Initially since most of the nitrogen will be tied up as nitrate in the regolith, microbes will carry out two processes under (low oxygen) conditions. Denitrification converts nitrate to gaseous dinitrogen, increasing the amount in the atmosphere. Assimilatory nitrate reduction by other microbes converts nitrate to ammonium ion and hence into organics. Once in organics, nitrogen cycles through microbes which die and release ammonia which is then reabsorbed and converted back into organics. Although nitrogen fixation is an anaerobic process, it cannot proceed until the atmospheric pressure of dinitrogen rises to about 5 mbar (Klingler *et al.* 1989). Once denitrification raises N_2 to this level, atmospheric dinitrogen can be converted directly into organic matter in microbes.

At this point a diverse and widespread assemblage of microorganisms will have established a microbial biosphere on Mars. Their metabolic activities will transform the regolith into a true soil by adding organics as wastes and dead cells. There appear to be few obstacles to a microbial biosphere on Mars.

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