ICARUS 20, 513-514 (1973)

Planetary Engineering on Mars

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Received July 20, 1973

Some 10^9 to 10^{10} metric tons of low albedo material, transported during the course of a century to the permanent Martian polar caps, may be capable of rapidly transforming Mars to much more Earth-like conditions. Alternatively the introduction to Mars of a dark plant which grows on the polar snows might accomplish the same objective. Fortunately neither program is a practical engineering venture for the near future.

As our at present faltering knowledge of the nearby planets improves, the opportunity may arise to alter their contemporary environments into ones which are for various reasons more appropriate to human activities. Some suggestions for doing this on a very grand scale—conceivable only in the remote future—have been put forth by Dyson (1959). A somewhat more modest suggestion, using the built-in amplification of biological replication, has been proposed for seeding the clouds of Venus with hardy algae—which, through photosynthesis, might simultaneously reduce the greenhouse effect to manageable proportions and increase the atmospheric oxygen abundance (Sagan, 1961). The most recent spacecraft results, indicating that appreciable sunlight is transmitted to the surface of the illuminated hemisphere of Venus (Marov *et al.*, 1973), strongly support the greenhouse mechanism implicit in the foregoing suggestion; but the probable identification of a 75% solution of sulfuric acid as the principal constituent of the upper clouds (Young, 1973) sets some further boundary conditions on the hardiness of the proposed organisms.

In the case of Mars a pre-Mariner 9 suggestion was made (Sagan, 1971) that Mars alternates between its present environment and one which is much more Earth-like; and that this climatic variation may be connected with the precession of the Martian equinoxes. Pursuing this idea, Burns and Harwit (1973) have discussed mechanisms for accelerating the natural equinoctial precession of Mars so that the clement conditions can be brought about in times $\leqslant 10^5$ yr. They considered altering the orbit of an asteroid or of a moon of Mars. These schemes did not seem quite able to provide an adequate celestial mechanical perturbation, and were—needless to say—expensive.

Subsequently Mariner 9 has uncovered a range of evidence—particularly the sinuous dendritic channels—which seem to imply that earlier more clement conditions have indeed occurred on Mars; and a more detailed model of climatic instability on Mars involving the advective transport of heat from equator to pole has been developed. In this model (Sagan, Toon, and Gierasch, 1973) three possible driving mechanisms of the natural climatic instability on the planet are proposed: variations in the planetary obliquity, variations in solar luminosity, and changes in the albedo of the polar cap. The last mechanism may be connected with the precession of the equinoxes, since great dust storms may be generated only when, as now, the perihelion and the summer solstice coincide in time. For all three driving mechanisms the appropriate fluctuation must be maintained for at least a century.

Of the three mechanisms it is clear that the easiest to generate artificially is a decrease in the albedo of the permanent

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polar cap—which heats the cap, increases the atmospheric pressure, improves the efficiency of advective heat transport from the equator to pole, which in turns heats the caps still further, and so on. The calculations show that a decline in the albedo of the permanent polar cap of only a few percent below contemporary values is adequate to drive such an advective instability. It is easy to calculate that with the addition of material of albedo $\leqslant 0.25$, only a 5–8% cover of the permanent polar cap is required to reduce the net albedo of the polar cap by a few percent. Since the typical albedo of Martian bright areas is about 0.25, sustained annual dust storms appear quite capable of naturally driving the instability, and Mars may today be emerging from a global ice age for this reason.

Alternatively we can ask how much material must be deposited on the permanent polar caps artificially in order to drive the instability at will. I assume that a 1-mm cover of low albedo material, such as carbon black, over 6% of the area of the polar caps will suffice. The required mass of C to be thus deposited is $\sim 10^8$ metric tons. This is about 10^8 times our present capability to land payloads on Mars with Titan/Centaur class missions. Alternatively the mass to be deposited is the equivalent of the transport to Mars and pulverization of a small asteroid of 300 m radius. Since once each Martian year there may be a strong surface transport of dust from the pole equatorward (Sagan *et al.*, 1973), the preceding numbers may have to be multiplied by a factor of 10 or 100 before the instability runs away. Thus this method for reengineering Mars for human purposes is only slightly less difficult than the celestial mechanical proposals of Burns and Harwit. This is probably all to the good: it is obviously unwise to perform a major alteration in a planetary environment before that planet has been thoroughly explored.

However, as in the case of Venus, the use of biological amplification might substantially reduce the necessary freightage. What is needed is a dense covering of low albedo plants, capable of growing on ice under contemporary Martian conditions. The organisms would have to survive dozens of Martian winters. To the best of my knowledge no such organism is known. But Martian conditions are by no means too severe for some terrestrial organisms, and laboratory selection experiments could be attempted. Again the development of such an organism should be attempted, as in the case of Venus (Sagan, 1961), only after a thorough and ecologically responsible program of unmanned planetary exploration has been completed.

By the time Mars is thoroughly explored, human technology may well have reached the point where it will be possible, in a short period of time, to reengineer Mars into a world with much higher pressures and temperatures, and much larger abundances of surface liquid water than are now present on the planet.

Acknowledgments

This research was supported in part by NASA Grant-NGR-33-01-101. I am greatly indebted to Freeman Dyson and Peter Gierasch for their comments on these speculations.

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