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THE LONG WINTER MODEL OF MARTIAN BIOLOGY: A SPECULATION*

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Abstract

An estimated mean thickness ~ 1 km of frost in the Martian North Polar Cap summer remnant, if vaporized, would yield $\sim 10^3$ g cm^{-2} of atmosphere over the planet, higher global temperatures through the greenhouse effect, and a greatly increased likelihood of liquid water. Vaporization of such cap remnants may occur twice each equinoctial precession, and Martian organisms may now be in cryptobiotic repose awaiting the end of the long precessional winter. The Viking biology experiments can test this hypothesis.

Some scientists, including some biologists, have been dismayed when confronted with the apparent inclemency of the present Martian environment. With global mean temperatures $\sim 210^{\circ}K$, diurnal temperature fluctuations in excess of 100 K° at equatorial latitudes, mean surface pressures hovering uncomfortably near the triple point of water, no detectable oxygen, an ultraviolet flux which delivers the mean lethal dose to typical unprotected terrestrial microorganisms in seconds, and a surface at one time widely advertised as "moon-like," some initial reserve about the habitability of Mars does seem to be in order. While it has been argued (Vishniac, et al., 1966; Sagan, 1970) that none of these environmental parameters provides insuperable physical or chemical obstacles to an indigenous biology, others have contended that the likelihood of such an indigenous contemporary biology on Mars is very small; and in some circles numbers such as 0.1% or less are fashionable. It is sometimes held that even if the probability of an indigenous biology is as low as 10^{-3}, the significance of finding such a biology is so enormous that the product of probability and significance still implies the importance of searching for Martian organisms. In fact *a priori* estimates of the probability of life on a particular planet are not possible in our present state of ignorance, and such probabilities are merely scepticism indices, calibrating the frame of mind of the speaker. Nevertheless such arguments have the entertaining consequence that they introduce into the field of discourse models of the Martian environment which have probabilities of 0.1% or less of being correct. One category of alternative model is contemporary microenvironments (Lederberg and Sagan, 1962); that is, locales on Mars which may have an integrated area $< 10^{-2}$ the total surface area, but which harbor much more clement conditions. I wish here to propose a different model--a microenvironment, not in space, but in time.

While the Martian south polar cap (SPC) is reported to disappear in southern summer, the Martian north polar cap (NPC) has never been known to vanish. The remnant summer NPC, offset from the aereographic north pole, has an area $\sim 10^5$ km^2. Since the remnant cap remains at the frost point, frost evaporating at the edge of the cap must largely be redeposited on the cap itself, and the thickness of the NPC may be considerable. Because of the obliquities and orbital geometries of Mars and the Earth, the north pole is averted away from Earth and is in darkness at favorable oppositions. It has also never been observed from spacecraft, and is unlikely to be viewed by the 1971 Mars Orbiters, unless their operational lifetimes considerably exceed the expectation value of 90 days.

The SPC has been observed in southern spring by Mariners

6 and 7--the thinner of the two frost covers, viewed when the frost was partially dissipated. From observations of craters partly obscured by frost, and other geomorphological criteria, the Mariner 6 and 7 experimenters concluded that frost thicknesses as great as many tens of meters were in evidence, and that regions of still greater thickness, perhaps partly buried under a dust overburden, were likely (Sharp, Murray, Leighton, Soderblom, and Cutts, 1971). Photographic evidence for a depositional interface, as well as the appearance of the parallel arcuate ridges near the south pole, led Belcher, Veverka and Sagan (1971) to suggest the presence of a large glacial morraine in the vicinity of the south pole, and the presence of ice ages on Mars.

The thickness of the NPC remnant is difficult to estimate reliably, but must be much deeper than these estimates for the SPC at some distance from the pole in local spring. I will assume that the appropriate value for the remnant NPC thickness is ~ 1 km, although an order of magnitude revision downward, and any plausible revision upward, will not significantly affect the argument. The area of the NPC remnant is $\sim 1\%$ that of Mars. If we consider the frost to have a local density ~ 1 g cm^{-3}, an arresting conclusion emerges: if the NPC remnant could be vaporized, it would yield $\sim 10^3$ g cm^{-2} of gas over the whole planet. There would be as much atmosphere on Mars as on the earth.

With the Martian NPC remnant completely evaporated the widespread presence of liquid water on the planet would be much more likely than it is today. Furthermore, through the greenhouse effect the planetary surface temperature would be considerably above present values. An atmosphere of 70 m-atm CO_2, pressure-broadened by a neutral gas at 1 bar pressure, plus 1 g cm^{-2} of water would increase the mean temperature by > 30 K^o, and therefore greatly increase the fraction of the disk above the freezing point of water each day. In the expectation that the polar cap is largely frozen CO_2, with more than 0.1% water, the incremental greenhouse effect would be larger yet. The proposal (Broida, et al., 1970) that ozone and other gases are trapped in the Martian polar caps raises still more interesting possibilities. The presence of CO in the Martian atmosphere implies that the net conditions may be reducing. It is therefore not out of the question that small quantities of such gases as methane and ammonia may also be trapped in the polar cap. If as much as 10^{-5} ammonia and methane is present, an additional 10 K^o greenhouse results. It seems apparent that epochs of major dissipation of the NPC remnant may dominate Martian biology.

In this view, we happen to be observing Mars at an inpropitious moment--when almost all the atmosphere is frozen out in the NPC. Under what conditions might this atmosphere return to the gas phase? Leighton and Murray (1966) have pointed out that an effective 5×10^4 year period of equinoctial precession applied to Mars. At the present time the NPC remnant exists in the north because the northern hemisphere is averted from the Sun at perihelion. Fifty thousand years from now the situation will be reversed, and a permanent SPC remnant can be expected. But what is the situation at an intermediate point in time, when the line of equinoxes is along the line of apsides of the Martian orbit and both poles are heated equally? The solar constant at Mars and the latent heat of vaporization of solid CO_2 imply an upper limit ~ 1 cm of frozen CO_2 vaporized per day. We neglect conduction and atmospheric transport. Thus substantial quantities of polar cap material can be vaporized in times very much shorter than the precessional cycle--indeed, in times not much longer than one Martian year. Midway through the precessional cycle the situation may be uninteresting: roughly equal amounts of cap material at each pole. But, considering the greenhouse and other instabilities inherent in the problem, it is also possible that a major fraction of the present NPC remnant is then converted into a denser Martian atmosphere, and that there is a precessional spring of a few thousand years duration in which conditions on Mars are far more clement than they are today.

The biological consequences of this hypothesis are straightforward. The bulk of Martian organisms shut up shop for the (precessional) winter. Spores, vegetative forms, and--

for all we know--hibernators abound, but only a few or no active organisms. At first sight, the Viking biology experiments will have arrived ten thousand years early. But on Earth hibernators are aroused, spores germinate, etc. because of a complex set of vernal cues--the principal of which being higher temperatures and increased availability of liquid water. The Viking biology package is, entirely by accident, ideally configured to test this hypothesis. Two experiments are designed to be performed with little or no liquid water (Horowitz, Hubbard, and Hobby, 1972; Oyama, 1972) and two in the presence of liquid water (Vishniac, 1972; Levin, 1972). Indeed the latter two experiments have been criticized on the grounds that liquid water does not exist on Mars and that any Martian microorganisms introduced into these experiments will drown. Instead, these experiments may provide local microbial waterholes, coaxing cryptobiotic forms into precocious biological activity. Spores and vegetative forms on the Earth are known to survive under very harsh conditions for hundreds of years and probably longer; there should be no difficulties with the survival of Martian cryptobiotic forms for $\sim 10^4$ years.

A mean planetary cover of a few cm of liquid water present for, say, 10% of the precessional cycle would be entirely adequate for a complex biology, and would provide a very useful source of additional erosion on Mars (see, e.g., Chapman et al., 1968; Hartmann, 1971). It would not introduce observational contradictions such as abundant estuaries and river deltas. Indeed, small amounts (several tens of μ) of liquid water on the Martian surface today have been inferred from the Martian microwave spectrum (Sagan and Veverka, 1971), and may be a contemporary vestige of the waters of the precessional spring. With the low Martian exospheric temperature there is no problem that such an intermittent atmosphere would escape in times short compared with the lifetime of Mars.

If there is a large residue of condensed volatiles in the NPC remnant, estimates of the mass budgets of Martian outgassing during the history of the planet will have to be revised upwards. I do not here broach the question of whether conditions in the very earliest history of Mars were suitable for the origin of life, but merely note that conditions appropriate for the origin of life on primitive Mars are exhibited in at least some scenarios (Sagan and Mullen, 1971).

Finally it is just conceivable that, in time, human endeavors could, by volatilizing the present NPC remnant, and taking advantage of the hypothesized instabilities, introduce much more clement conditions on Mars, in times considerably shorter than the precessional period. As with a related suggestion for Venus (Sagan, 1961), such planetary engineering should be considered seriously only after the most thorough and ecologically responsible investigation of the planet is performed.

The critical link in this chain of hypotheses is the assumption that adequate instabilities exist during Martian precessional springs to release in vapor phase the materials now trapped in the Martian North Polar Cap remnant, and that it is possible to recondense such a vaporized polar cap later in the equinoctial precession (i.e., that the instabilities are reversible). I cannot estimate the probability that such instabilities exist, but I guess on intuitive grounds -- the same grounds utilized for *a priori* estimates of the habitability of Mars -- that these probabilities are not insignificant, and are perhaps even $\geq 10^{-3}$,

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