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The Search for Extraterrestrial Life

Present knowledge does not permit the conclusion that, if life ever existed on Mars, it is now extinct.

N. H. Horowitz

The discovery of life on another planet would be a monument to our age. Not only would it be an unparalleled technological achievement, but it would be a momentous scientific event that would enlarge our view of nature and ourselves and provide unique evidence bearing on the origin of life. In this article, I am going to discuss the coming search for life on Mars. Venus, our other close neighbor among the planets, has been excluded from consideration, for the time being at least, because its high surface temperature—in the neighborhood of 400°C—seems incompatible with life or, for that matter, with much organic chemistry of any kind. The planets of the solar system beyond Mars are out of reach for the present.

The Martian Environment

I have given the reason for thinking that if life ever existed on Venus, it does so no longer. What can be said about Mars? We can say that although the situation is not brimming with hope, neither is it hopeless. The Martian environment is a harsh one by terrestrial standards. The mean temperature is −55°C, compared to +15°C for the Earth. The atmosphere is thin and very dry; it contains carbon dioxide and a small amount of water vapor, but no detected oxygen. Owing to the low density of the atmosphere and the absence of a magnetic field, the surface of Mars is bombarded by cosmic rays and solar radiation in an almost unattenuated form, as O'Gallagher and Simpson have recently pointed out (*1*). Finally, the Mariner IV photographs give the definite impression that Mars is geologically a dead planet whose surface has been undisturbed by anything except meteorite impacts for a very long time and which lacks the great variety of ecological habitats that characterize the Earth (*2*).

This is all very depressing news for biologists, but if I have learned anything during 6 years of association with the space program, it is that people with manic-depressive tendencies should stay out of it. Our knowledge of planetary environments is still fragmentary, and one's subjective estimate of the likelihood of finding life on Mars is liable to undergo violent fluctuations from time to time as new data accumulate. The fact is that nothing that we have learned about Mars—in contrast to Venus—excludes it as a possible abode of life. Martian temperatures are not very different from those of Antarctica, where a varied microbial life, and even a few flowering plants and invertebrate animals, have been found (*3*). Although the mean temperature on Mars is low, the seasonal and diurnal fluctuations are great, and temperatures as high as 25°C have been measured near the equator.

Radiation Flux on Mars

The ionization produced at the surface of Mars by cosmic rays is several hundred times greater than that found on the Earth, which is shielded by 1033 grams of atmosphere per square centimeter, but it is still far below a level that could be considered hazardous for life—even a slowly reproducing form of life. The dose rate calculated from O'Gallagher and Simpson's estimate of the ion density at or near the Martian surface is about 20 millirads per day, whereas the mean lethal dose for a typical bacterium (*Escherichia coli*) is in the neighborhood of 5000 rads. A greater potential hazard is posed by the solar far-ultraviolet light which, according to a recent report (*4*), penetrates to the Martian surface. Wavelengths in the neighborhood of 2600 angstroms are highly lethal for unprotected cells. On the

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Earth, these wavelengths are removed by ozone in our upper atmosphere. At the distance of Mars, the flux of solar ultraviolet in the 2400- to 2800-angstrom range exceeds 20 ergs per square millimeter per second (*5*). This quantity of radiation is sufficient to kill the most resistant terrestrial bacteria in a matter of minutes. Ultraviolet is strongly absorbed by many substances, however, so that it would not be difficult for Martian organisms to be protected against it. If a substantial fraction of this radiation reaches the surface of Mars, it would be a significant factor in protecting the planet against accidental contamination by terrestrial microorganisms, and it obviously should be taken into account in determining spacecraft sterilization standards. This is a large and complex subject which I will not attempt to discuss here.

Scarcity of Water

The scarcity of water is probably the most serious limiting factor for any Martian biology. The atmosphere of Mars contains approximately 14 microns of precipitable water, or roughly 1/1000 the amount found in our atmosphere (*6*). Polar ice caps that wax and wane with the seasons are seen on the planet, and it has been suggested that permafrost may be found beneath the surface. No permanent bodies of liquid water can exist there, however, because Mars is below the triple point for water. It has been argued that the lack of water excludes the possibility of life as we know it on Mars. It is certainly true that no terrestrial species could survive under average Martian conditions as we know them, except in a dormant state. But if we admit the possibility that Mars once had a more favorable climate which was gradually transformed to the severe one we find there today, and if we accept the possibility that life arose on the planet during this earlier epoch, then we cannot exclude the possibility that Martian life succeeded in adapting itself to the changing conditions and survives there still.

Many terrestrial species are adapted to life in dry environments—in deserts, for example, or in saturated brine, as in the Dead Sea or the Great Salt Lake. One of the most interesting drought-loving forms is the kangaroo rat of the Mojave Desert in Arizona and Southern California. This little animal has been studied by Schmidt-Nielsen (*7*), who finds that it can live indefinitely on air-dried barley without ever drinking water. All its water is produced metabolically by the oxidation of carbohydrates. It can survive in this way at relative humidities as low as 20 percent—that is, in an atmosphere in equilibrium with 60 percent sulfuric acid. If the kangaroo rat is fed on soy beans, it requires water in order to excrete the extra urea produced by this high-protein food; but it can then thrive on sea water. The urine of the animal contains twice as much salt as sea water does.

Even Southern California is not as dry as Mars, and I am not suggesting that Mars is inhabited by kangaroo rats and that the first life-detection device on Mars should be a mousetrap. I am citing this example merely in order to show what evolution can accomplish. The point was made very clearly in a recent cartoon by Mauldin in which a flying saucer carrying two obvious Martians is shown. One Martian is inspecting the Earth through field glasses and is saying to the other: "A planet three-quarters covered with water couldn't possibly support life."

The biological implications of the Mariner IV photographs of Mars have been widely discussed. These photographs show a densely cratered surface resembling that of the Moon. If the rates of meteorite impact on Mars and the Moon are the same, then the Mariner pictures mean that the craters seen on Mars are the same age as those on the Moon—that is, up to 5 billion years old. The fact that such ancient craters are still visible would imply the virtual absence of weathering on the face of Mars; this, together with the failure to detect any signs of river valleys or ocean beds, would lead to the conclusion that the condition of Mars as we see it today is not very different from that of primordial Mars. If this were so, there would be little reason to suppose that life had ever evolved on the planet. The question of the relative rates of meteorite impact on the Moon and Mars is critical for this argument, however. Recent discussions of this problem (*8*, *9*), indicate that in all probability Mars has been subject to a much higher rate of crater-forming impacts than the Moon. It follows that the craters seen on Mars are younger than those of the Moon, and no conclusions can be drawn from the photographs about the nature of earlier Martian environments. The greatest possible age for the Martian craters, according to Anders and Arnold (*8*), is 800 million years. But fossil remains of highly evolved types of microorganisms have been found in Precambrian rocks approaching 2 billion years old (*10*). Clearly, then, it would be dangerous to conclude from the evidence now available that life never evolved on Mars.

I cannot leave this subject without emphasizing that not all the evidence bearing on this question is negative. The phenomenon that first led astronomers to suggest that Mars is an inhabited planet—the seasonal change of color in the maria, or dark regions—is still unexplained. This effect is described as a wave of darkening that starts at the edge of the melting polar ice cap in the spring and progresses toward the equator as the season advances. The color of the maria changes from grayish to violet, although some observers have reported vivid greens and blues. By midsummer, the wave reaches the equator; then, with the approach of winter, the color fades. It is generally agreed that the phenomenon is associated with the seasonal translocation of water vapor from one pole to the other. It could thus reflect the growth of vegetation, stimulated by the availability of water, or it could result from an inorganic process such as the uptake of water by hygroscopic salts. The biological explanation readily accounts for one striking fact; namely, that the maria continue to reappear despite the great dust storms that sometimes obscure the entire disc of the planet. This regenerative capacity suggests that something in the maria is capable of growing up through the dust layer. It is of interest to note that there is an indication in the Mariner IV photographs, supported by recent radar experiments, that the maria correspond to heavily cratered regions.

Objectives and Tactics of Martian Biological Exploration

Coming now to the tactics of Martian biological exploration, let me first state the initial objectives. They are twofold: first, of course, to determine whether there is life on the planet; second, and equally important, to learn whether Martian life, if it exists, is independent in origin from life on the Earth. I will consider here only the first of these twin objectives, since this is the only one we can hope to accomplish in the next decade. Current theories about the history of the solar system and the origin of life suggest that conditions on primitive Mars may have been sufficiently like those of the primitive Earth to have made possible an independent origin of life (*11*). But if life is found on Mars, it cannot be *assumed* to have had an independent origin. To get the answer would require a careful study of the chemical organization of Martian life. We would want to know, for example, whether Martian protoplasm contains nucleic acids and proteins, and if so what their composition is. We would have questions about the optical activity of Martian amino acids, about the Martian genetic code, and so forth. These are difficult questions. To get answers to them in a reasonable length of time may require the return of Martian samples to the Earth for study in terrestrial laboratories. This may not be so far-fetched as it sounds; informed people are already talking about manned missions to Mars by 1985. In this discussion, however, I will consider only life-detection experiments that could be carried out by unmanned spacecraft that land on the surface of Mars. The possibility of performing an unambiguous life-detection test from a flyby or an orbiter is remote. To solve this problem, we will probably have to land a capsule on Mars and have it survive long enough to make some measurements and transmit them back to Earth. This is not an easy task, but no Mars mission is easy.

In designing life-detection experiments, certain fundamental principles have to be observed. In the first place, the best experiments are those that make the fewest unsupported assumptions about the nature of Martian life and the Martian environment. Second, it is essential that the program of life-detection tests be of such a nature that positive results will be strongly indicative of the presence of life, and cumulative negative results will provide credible evidence of its absence. On both scores, a series of high-resolution visual scans of the Martian terrain, including a TV-microscope system, would be nearly ideal. Such scans of a number of selected areas would be of great interest not only for biologists, but for other scientists as well—and, I imagine, for nonscientists, too. Unfortunately, the same quality that makes photographs so valuable—their high information content—also makes them very expensive to transmit, in terms of the power required. The capacity of the communication link to transmit information—its bit-rate capability—may not be high enough on early missions to send many pictures. Besides, we need more information than pictures alone can produce. For these reasons, it is desirable to develop low-bit-rate experiments which are capable of yielding useful data. As an example of such an experiment, I will mention one whose development I have been associated with. This device, which has been called "Gulliver" by its inventor, Gilbert V. Levin (*12*), is representative of a number of experiments being developed under the sponsorship of the National Aeronautics and Space Administration to detect microbial life in Martian soil. By searching for microorganisms, it is hoped to maximize the chance of success. Microorganisms are ubiquitous on the Earth, and they survive in extreme environments. Microbial life could conceivably be the only form of life on Mars, but it is hard to imagine there being life on Mars without microbes. For the purposes of fundamental biology, it would be just as valuable to find microbial life on Mars as higher forms. Any form of Martian life would be intensely interesting to science. From a fundamental viewpoint, there is only one form of life on the Earth. All species are constructed out of the same few building blocks; despite appearances, the differences between species are relatively superficial. The question we ask is whether another form of life exists on Mars.

The "Gulliver" Experiment

"Gulliver" is a culture chamber that inoculates itself with a sample of soil. The sample is obtained by two 7½-meter lengths of kite line wound on small projectiles. When the projectiles are fired, the lines unwind and fall to the ground. A small motor inside the chamber then reels them in, together with adhering soil particles. The chamber contains a growth medium whose organic nutrients are labeled with radioactive carbon. When the medium is inoculated with soil, the accompanying microorganisms metabolize the organic compounds and release radioactive carbon dioxide. This diffuses to the window of a Geiger counter, where the radioactivity is measured. Growth of the microbes causes the rate of carbon dioxide production to increase exponentially with time—an indication that the gas is being formed biologically. Provision is also made for the injection, during the run, of a solution containing a metabolic poison which can be used to confirm the biological origin of the carbon dioxide and to analyze the nature of the metabolic reactions.

The choice of nutrients for the Gulliver medium—especially the organic nutrients—is obviously a matter of central importance. I will not take time here to explain why we assume that Martian life would be based on carbon and not, for instance, on silicon. This question has received considerable attention in the past (*13*). There is general agreement that carbon is uniquely qualified among the elements for forming the large and complex kinds of molecules that we associate with life. We know also that the Martian atmosphere contains large quantities of carbon dioxide—in fact, this is its principal constituent. If there is life on Mars, then it is a reasonable assumption—indeed, I believe it is a necessary consequence—that its carbon cycles through this atmosphere. We would expect to find on Mars, as we find on Earth, a continual exchange of carbon between the atmosphere and the biosphere.

The problem of selecting organic substrates is common to Gulliver and other experiments designed to culture Martian microbes. What we need are organic substances that are widespread in the solar system and that are known to have a biological function on the Earth. This problem can be approached experimentally. In fact, the experiment has already been done: It is the well known Urey-Miller spark-discharge reaction (*14*). This experiment demonstrated the production of a variety of biologically important organic compounds when a spark discharge was passed through a mixture of gases believed to resemble those of the Earth's primordial atmosphere. Since the primitive atmospheres of Mars and Earth were probably similar, it is reasonable to suppose that the same compounds were formed in large amounts on primitive Mars. Many of these substances —for example, formate, lactate, and glutamate—are readily metabolized to carbon dioxide, and they are therefore a natural choice for a cosmic culture medium.

Photosynthesis

Radioactive carbon can be used in another kind of experiment that makes even fewer assumptions about the nature of Martian life than does Gulliver. It can be used to detect photosynthesis—that is, the light-dependent fixation of carbon dioxide. A number of instruments specially designed to detect photosynthesis are currently being developed under NASA sponsorship. One of the strongest statements that can be made about Martian biology is that if there is life on the planet there must be at least one photosynthetic species. This is so because the sun is the only inexhaustible source of energy in the solar system. All life on the Earth depends ultimately on those species which are capable of utilizing solar energy. This includes the chemoautotropic bacteria which obtain energy by the oxidation of inorganic matter; these organisms would soon exhaust their sources of supply if they were not continually replenished by the activity of photosynthesizers. Since photosynthetic organisms must receive light from the sun, this argument leads to the corollary that, if there is life on Mars, some of it must live on the surface. There is no use imagining that if there is no life at the surface it may be found under rocks or in caves. The presence of little or no oxygen in the atmosphere of Mars does not, of course, rule out the possibility that photosynthesis is occurring there. On the Earth, green-plant photosynthesis produces oxygen, but bacterial photosynthesis does not. This difference results from the fact that bacteria do not use water for the reduction of carbon dioxide, but other reducing agents. The same could be true on Mars, but since the planet is apparently hydrogen-poor, the nature of the reducing agent poses a major problem.

Other experiments being developed for the biological exploration of Mars include automatic instruments for the analysis of the atmosphere and soil, with special reference to substances of biological importance, and for detecting net optical activity in soil extracts *(15)*.

Summary and Conclusions

In summary, current theories about the history of the solar system and the origin of life suggest that conditions on primitive Mars may have been sufficiently like those of the primitive Earth to have made possible an independent origin of life. The present environment of Mars is extremely harsh, but our knowledge of it does not permit the conclusion that, if life ever existed there, it is now extinct. Indeed, certain phenomena associated with the change of seasons suggest the growth of vegetation of Mars, although other explanations are not excluded. A number of automatic devices designed to detect microbial life, or the products of microbial activity, in Martian soil are currently being developed. It is hoped that these instruments, combined with high-resolution photography, will give an answer to the question of life on Mars in the next decade. A positive answer would immediately pose questions concerning the chemical nature of Martian life. How we will go about getting answers to these questions, should they arise, we cannot now predict.

In closing, let me say that, in my personal opinion, the chance of finding life on Mars is clearly not zero, but neither is it very high. Certainly, there is little in the Mariner IV and other recent data to make one confident on this score. It is not optimism about the outcome that gives impetus to the search for extraterrestrial life; rather, it is the immense importance that a positive result would have. One has to multiply the first of these somewhat subjective quantities by the second to find the scientific worth of the Mars undertaking. The argument of this article is that the value so obtained is high.

Of course, even a lifeless Mars could be of great biological value if it yielded fossils or yielded organic chemicals of a prebiological era. In respect to the latter point, the Moon, too, may be of considerable interest. These are questions for the future. For the present, we can say that while Mariner IV neither proved nor disproved the existence of life on Mars, it did demonstrate that we now have the technology necessary to get the answer; indeed, this demonstration was the most important result of the mission. Whatever the final answer to the question of life on Mars may turn out to be, the search will be one of the great scientific and engineering enterprises of the 20th century.

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