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Synopsis of Martian Life Theories

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I. Introduction

Ever since the introduction of the telescope into astronomy, when Galileo Galilei revealed that the wandering stars are different from the fixed stars and more similar to our planet, speculation about life outside the Earth has occupied the human mind. And, when linear markings and seasonal color changes of the dark blue-green areas on the surface of Mars were observed, the red planet became the focal point of lively discussions as a possible abode of life. The apparent geometric pattern of some of the linear dark markings, called "canali" in 1877 by Schiaparelli [1], led Lowell, in 1906 [2], to assume they were the engineering work of intelligent beings. This belief is no longer held, but the possibility of some kind of life on Mars has been the subject of many pro and contra arguments during the past decades.

The study of extraterrestrial life applied to Mars, conveniently called *Mars biology*, plays the dominant role in the broader field variously termed *astrobotany* [3], *astrobiology* [4, 5], *exobiology* [6], and *cosmobiology*. Numerous books dealing specifically with this subject as well as chapters in related books, have been published during the past decades [7–43]. The number of articles now approaches 1000.

Today, with the fast development of astronautics, Mars is considered the first postlunar objective for a manned planetary landing mission. An evaluation of its environment from a human physiological or medical point of view, therefore, is becoming an important task of what we might call Martian environmental medicine or, briefly, *Mars medicine* [44].

All of these speculations and scientific evaluations received a strong impetus by the Martian fly-by probe, Mariner 4, July 14, 1965, the results of which have opened new vistas, have confirmed older theories, and require revision of others.

In the following paragraphs, the question of life, or the possible existence of a biosphere on Mars will be discussed in a synoptic form.

The term "biosphere" [45] is used for those regions on Earth in which organisms are found. It also is applied to denote the living world as such. For the highest level of the biosphere, distinguished by intelligence, the term "*noosphere*" (from Greek, nous = mind) has been suggested [45].

II. Interpretation of the Dark Areas

The Martian life theories have been stimulated by and are concentrated upon the dark surface areas, called *maria* (= seas), and dark spots, called *oases*; they are generally localized in the same regions and are permanent, representing about one-third of the total planetary surface. Their seasonal color variations from dark gray in winter, bluish-green in spring, yellow-gold in summer, and brown in fall have been the reason for the belief that there might be plant life on Mars.

A. Optical Color Dispute

But there are some arguments about the bluish-green color. To some astronomical observers, the areas in question always appear to be dark gray. In this respect, it must be emphasized that a prerequisite for the reliability of any visual color observation is a medically tested normal color vision of the observer. We must remember that 7 per cent of the male population is color defective.

The bluish-green color is also considered to be a visual contrast phenomenon against the ochre-red surroundings. Visual contrast effects certainly occur, especially if the areas are small, but the bluish-green coloration of large areas such as the Syrtis Major is in all probability real [46]. This is also supported by the observation of Tombaugh [47], who recently reported that certain areas occasionally look dark when others look green, despite the fact that both are surrounded by reddish areas. But green or not green, it is not decisive for life "to be or not to be" on Mars.

B. Inorganic Chemical Explanation

Arrhenius [9] advanced the theory that the dark areas are salt beds of dried out oceans which respond to small changes in atmospheric humidity and came to the conclusion that "Mars is indubitably a dead world."

In a similar inorganic way, the dark areas have been explained as being deposits of volcanic ash blown over them by the prevailing winds [48]. Their color changes are attributed to reactions to seasonal variations in humidity or to intensity fluctuations of radiation. This, of course, does not exclude the possibility of life, because terrestrial bacteria, lichen, and mosses can grow on lava.

Recently, the color variations have been explained by a change of nitrogen tetroxide (N_2O_4) to nitrogen dioxide (NO_2) and back, depending on temperature fluctuations [49]; if these nitrogen oxides were present in the atmosphere and on the ground, they would exclude life because of their toxicity. Recently, their significance on Mars has been questioned [50].

C. Organic Chemical (Biological) Interpretation

The spectroscopic observation of absorption bands in the infrared, near 3.6 μ and found only in the dark areas, has been interpreted as an indication of the presence of organic molecules [51]. A recent re-examination showed that they conform just as well with the absorption bands of certain inorganic molecules, particularly of heavy water [52].

Comparative polarimetric [53] and spectroscopic studies [54] of the dark green areas on Mars, and of terrestrial green plants, are also in favor of the vegetation theory.

After a heavy dust storm, the whole planet appears reddish, as was the case in 1956; but, several weeks after such events, the dark areas reappear. This, according to Öpik [55], can be explained only by assuming that some of the dark soil components must have regenerative power which, again, points to biologic material.

Very recently, methane has been detected in the Martian atmosphere and interpreted as an indication of the presence of organic soil material [56].

In geobiology, there are anaerobic bacteria that convert decomposed organic compounds via fermentation to methane. This "marsh gas," produced by these "methane bacteria" in oxygen-free environments such as at the bottom muds of ponds, upon rising to the surface into the atmosphere is then oxidized by aerobic bacteria. This latter process cannot be expected in the absence of oxygen on Mars, but "methane fermentation" is certainly conceivable.

As the result of these astronomical findings, the opinion of the proponents of the Martian life theory prevails that only lower, very hardy microorganisms (bacteria, algae, fungi), and lower plants such as lichen (fungi and algae in symbiosis) and mosses could exist under the adverse environmental conditions on Mars. However, some go farther and suggest even the existence of leaf plants; only this type of plants with broad surfaces could provide a visually observable greenish cover [57].

All in all, there are various suggestive indications but no substantiation for any of these Martian life theories; at present, they must be considered as speculations. But, we progress a step farther in our judgment about the possibility of a Martian biosphere by considering the physical environmental conditions on Mars and contrasting them with the tolerance capabilities of terrestrial life. Concerning the Martian physical environment, the following discussion is based on the status of our knowledge in 1966, which includes the results of the Mariner 4 fly-by probe.

III. The Martian Life Theories in the Perspective of Geoecological Criteria

In the following paragraphs, we shall examine the ecological potential of the Martian environment in terms of terrestrial biological criteria [58], such as "limiting factors" for active life or the so-called "cardinal points," the required minimum and the permissible maximum for life-supporting (biophilic) factors (matter and energies), and the permissible maximum concerning life-destructive (biocidal) factors. Beyond these two cardinal points, life is still possible in a dormant state, until it terminates at the "ultimum." The range of active life can be considerably extended by adaptation via life-supporting and protecting mechanisms.

The two Martian environmental spheres we have to consider are the ground-near atmosphere and the surface layer of the lithosphere or, more to the point, the interface between these two environmental spheres. Localized places such as valleys, craters, faults, caves, etc., which represent the microenvironment, may offer more favorable ecological conditions than the macroenvironment of wide open surface spaces.

In an attempt to contrast the various environmental components singly and in combination (found in all of these environments) against the aforementioned ecological criteria, we can resort to the abundant material found in the literature on microbiology, bacteriology, botany, and ecology and to the results of experiments in simulated environments (e.g., in environmental chambers) specifically applied to Mars [59–63]. The environmental factors in which we are interested are matter and radiational energy. Beginning with matter, the most essential elements for life are oxygen, hydrogen, carbon, and nitrogen. They must be available in their free molecular form or in chemical compounds, such as in carbon dioxide, water, and others.

A. Soil: Chemical Composition

The inorganic material of the dark surface areas on Mars is considered to be of the same kind as the composition of the reddish areas, resulting from very frequent and very heavy dust storms. Iron oxides, limonite, and felsite are mentioned as the main constituents [14, 64]. They contain elements of which life as we know it on Earth is composed. We shall return to this later.

B. Air Pressure

The earlier estimations of the atmospheric pressure at ground level on Mars, based on spectrographic studies, ranged from 85 to 10 mbar. The occultation experiment of Mariner 4 suggests a pressure of 10 to 5 mbar [65]; thus, the Martian atmosphere is 100 times thinner than the terrestrial atmosphere, and its pressure is equivalent to that found at about 30 km in the Earth's atmosphere.

Microorganisms and lower plants have survived pressures in the range from 80 to 10 mbar and lower in simulated experiments in planetary environmental chambers. Certain bacteria and spores, particularly, are resistant even to a vacuum [66].

C. Atmospheric Chemical Composition

The chemical composition includes carbon dioxide, nitrogen, argon, water vapor, and traces of oxygen, if any. Formerly, nitrogen was considered the dominant constituent; recent evaluation puts carbon dioxide in first place.

1. Oxygen

That oxygen is practically absent in the Martian atmosphere is certainly a life-limiting but not excluding factor. It is true that oxygen is the "element of life" (Lavoisier) for all organisms, which require it in its free form (O_2)

for the oxidation of the nutrient material (oxybiosis). This includes the plant and animal kingdom and man. But terrestrial microbiology knows of a large group of bacteria which does not need oxygen or is even sensitive to it (facultative and obligative anaerobic bacteria). Thus, anoxybiosis could be the way of life on Mars. But, if there are microorganisms possessing some kind of chlorophyl, they might produce their own oxygen by means of photosynthesis, and multicellular organisms with this capability might store it in intercellular air spaces of the kind found in terrestrial leaf plants and in lichens and mosses.

2. Carbon Dioxide

One of the basic raw materials for photosynthesis is carbon dioxide. In the Earth's atmosphere, the carbon dioxide pressure is 0.2 mm Hg; on Mars, it might be ten times as high. This would be of advantage for the growth of green vegetation, since increased carbon dioxide in this range promotes photosynthesis. Beyond 22 mm Hg, it has an inhibiting effect upon this carbohydrate-producing process. Besides the role of carbon dioxide for life, carbon itself is the structure atom of the carbohydrates. Terrestrial life is largely based on carbon biology. Since its atmosphere contains carbon dioxide, there are sufficient resources for carbon biology on Mars.

3. Water

Whereas oxygen is the functional element of life, and carbon the principle building atom of life, water is the basic solvent of salt and organic substances in the cells and has been the matrix medium for the evolution of life on Earth. Furthermore, it participates as a reactant in cellular metabolism. In green plants it is, in addition to CO_2, the raw material for photosynthesis.

In the Martian atmosphere, water vapor is extremely scarce. It amounts to only $\frac{1}{1000}$ of the general humidity of the terrestrial atmosphere. More important than the atmosphere's humidity is that of the soil. If the barometric pressure is below 7.5 mbar, it is below the "triple point" of water, i.e., H_2O can exist only in the state of vapor and ice. The latter is found, perhaps together with dry ice, in the polar caps. But in the lowlands, the barometric pressure might be around 10 mbar; in this case, H_2O could occur in the liquid state. The wave of darkening in spring, moving from pole to pole, is an indication of moistening. Water content of the soil is decisive for the existence of living organisms. Nevertheless, some terrestrial microorganisms, especially spores, can survive long periods of complete desiccation. Seasonal periods of complete dryness on the Martian surface would not prevent or destroy a Martian microorganismic biosphere. Furthermore, on Earth there are certain deserts with sometimes zero atmospheric humidity, and yet botany knows of many so-called "desert plants" that are able to store water and have developed specific membranes to prevent evaporation.

Hydroecologically, the situation on Mars is severe but not to the extent that it is prohibitive to life of the low-level terrestrial type.

4. Nitrogen

Nitrogen is the basis element of protein, the main chemical compound of the structure of living organisms. Most of them absorb this element from inorganic nitrogen compounds (nitrates) in the soil and living matter. However, certain plants host in their roots bacteria that build up protein from nitrogen in the air (nitrogen-fixing bacteria) for the plants. The latter, in turn, provide a suitable microclimate and protection for the bacteria. It would be strange if the Martian soil does not contain nitrogen compounds; in the Martian air, nitrogen is assumed to be the main or second most frequent element. Thus, microorganisms and plants should find on Mars adequate nitrogen resources.

After this review of matter in the soil-air interface, we now turn to radiational energies. This factor is related to some of the planetary orbital elements.[1]

D. Radiation

1. Temperature

The solar constant, or more specifically the thermal irradiance constant at the mean orbital distance of Mars, is 0.85 cal-cm^{-2} min^{-1} [67]. If we allow 20 per cent for absorption by the Martian atmosphere, then the thermal influx at the surface of Mars might be around 0.6 cal-cm^{-2}-min^{-1}. Exposed to this heat irradiance, the Martian surface can reach, during the afternoon, a temperature of +25°C [68]. The dark areas are some 5°C higher. During the night, before dawn, the temperature drops to −60°C and lower. This variation of about 100° occurs within a period of 24 hr, 37 min. The seasons are about twice as long as on Earth.

Could life, as we know it, tolerate such diurnal and seasonal temperature extremes? During most of the daytime in the lower latitudes on Mars, the temperature is ecologically adequate; it is the low night temperatures that are critical. Active life processes in terrestrial biology cease around −10°C, and most organisms do not survive. But others enter a dormant state (hibernation). Moreover, there are bacteria and spores that survive temperatures close to absolute zero. We know also that terrestrial organisms have developed mechanisms to absorb more heat by pigmentation, resulting in a

[1] Mean orbital distance = 228 × 10^6 km, period of revolution = 687 terrestrial days, and period of rotation = 24 hr, 37 min.

greater tolerance of very low temperatures [5, 15]. Organisms with a broad range of temperature tolerance are called eurythermal.

Protection against frost could be imagined if the Martian plants were able to produce some kind of antifreeze such as glycerol as a metabolic by-product. In fact, some of the terrestrial lichens contain erythrol, which belongs to the same class of chemicals as glycerol [17]. Considering the entire temperature range, Mars biology during the daytime in spring and summer would be moderate euthermal, but the cold night would turn it into a low-temperature biology, or cryobiology.

But locally there might be exceptions in the form of permanent warm spots on the surface similar to those found on Earth [15, 69]. For instance, on Mt. Wrangell, Alaska, there is a perennially warm, snow-free, volcanic sand area surrounded by snow and glaciers 4150 meters high. A laboratory constructed on top of this mountain by the Aerospace Medical Division (Brooks Air Force Base, Texas) in 1964 does not require heating at any time; it utilizes thermal output of an inactive volcano. Similar permawarm spots may exist on Mars, which would enjoy moderate temperatures during the night and therefore would have a higher ecological potential.

All in all, thermoecologically (from the standpoint of terrestrial biology), the climate on Mars should be no obstacle to very hardy, cold-resistant microorganisms and even lower plants.

2. Light

Light is the next important ecological energy factor for life. Chlorophyl-bearing green plants require light energy for the photosynthetic buildup of organic matter. But many species of nongreen microbes and plants can get along without it, as demonstrated by those found in caves, pores of the soil, underground water, and in the deep sea.

Solar illuminance at the mean orbital distance of Mars amounts to 60,000 lux, or lumens per square meter [67]. After penetration of the atmosphere at the surface, it might be still of the order of 30,000–40,000 lux. The required minimum in illuminance for photosynthesis lies around 2000 lux. There should be, therefore, during most of the sunshine time, enough light for this process.

Photoecologically, therefore, the conditions on Mars are well within the range of light requirement for the kind of photosynthetically active plants on Earth.

3. Solar Ultraviolet and X Rays

It has been argued that the low density of a 10-mbar pressure atmosphere may not provide effective protection from harmful solar ultraviolet rays and

X rays; but it must be remembered that solar irradiance at Mars' distance is less than half of that at the Earth's solar distance. Furthermore, a certain amount of these rays is certainly absorbed within the atmosphere. From biological research, it is well known that ultraviolet rays, particularly in the range from 2500 to 2800 Å, are indeed very destructive to most terrestrial microorganisms. For this reason, they are used for sterilization of food, and of lunar and planetary probes, to prevent contamination and back contamination [70].

There are various degrees of resistance to ultraviolet and X rays. It has even been reported that certain microorganisms are stimulated in growth when exposed to low-intensity solar ultraviolet and X rays [71]. Moreover, some microorganisms, plants, and animals are less susceptible to ionizing radiation under hypoxic and hypothermal conditions; this is particularly interesting with regard to Mars, where there is no atmospheric oxygen and a much lower temperature range than on Earth.

4. Particle Rays

Finally, energetic particle rays of solar and galactic origin, consisting essentially of protons, neutrons, and alpha particles, etc., are considered as possible adverse factors of life on Mars because they can reach its atmosphere unhindered by a magnetospheric shield [72]. On Earth, those primary particle rays that penetrate its atmosphere are transformed, when in collision with air molecules and atoms, into less powerful secondary and tertiary rays between 25 and 45 km. Assuming a Martian air pressure of 10 mbar, most of the primary rays might reach the surface; nevertheless, a certain amount may be converted into secondary rays. The absorption level at the bottom of the atmosphere on Mars may be equivalent to that at about 30 km in the Earth's atmosphere. Moreover, because of the greater distance from the Sun, the influx of solar particle rays is lower, and, finally, the microenvironment provided by caves, rims of craters, and fissures should offer additional radiation protection for life on Mars. It also should be noted that seed of barley kept completely sealed off from energetic particle rays (in the Simplon tunnel below the 2500-meter-high Monte-Leone in the Alps) does not grow as well as those exposed to the normal radiation environment on the Earth's surface [73].

E. Summary

An ecological evaluation of the various components of the Martian environment in terms of the geobiological principle of the limiting factors reveals no absolutely forbidding obstacles to life on Mars. But we cannot consider these various environmental factors separately; there are interrelations insofar as one factor can reduce or increase the life-supporting or destructive effect of another. Also of interest are the interrelations between various species within a community (synecology), and not only the relation of a single species to its environment alone. Furthermore, microorganisms can develop tremendous adaptabilities; bacteria can live practically anywhere, as indicated by the new biological branches: cryobiology and petroleum bacteriology. They are ecologically real cosmopolitans. The microclimates offer more moderate conditions, and, finally, living organisms can change the physical properties and chemistry of the atmosphere and soil. The material of the soil can change into humus (mineralized decomposed organic matter), making the soil more fertile for vegetation and giving it its crumblike granular character. Moreover, because of the colloidal properties of decomposed organic chemicals, the soil can absorb and hold more water. A greater moisture-holding power is partly responsible for the dark color of humus soil on Earth. A similar interpretation of the Martian soil in the dark regions is not out of line and would better explain the phenomenon of the wave of darkening mentioned earlier.

Considering all the physicochemical and biological factors and their interrelations, and particularly the adaptability of life to adverse conditions and the effect of living matter upon the soil, we must come to the conclusion that the occurrence of life on Mars is *more in the realm of probability* than of possibility. The dark areas on the Martian surface might indeed represent an ecological system, or ecosystem, but of a level far below that found on Earth. In terms of carbon biology and geocentric analogy, the conclusion is justified that the dark surface area can be of a biospheric nature.

The foregoing paragraphs all refer exclusively to the Martian surface; in the following, we shall discuss a theory about the deeper subsurface crust. This is important because the "geological" properties below can have a decisive influence upon the surface structure and its ecological qualities.

IV. Frozen Ocean Theory

One of the most conspicuous characteristics of the dark areas is their distinct location, permanence, and reappearance in the same region after duststorms. For 200 years, they have not changed their boundaries with the exception of minor invasions into the reddish areas. One explanation is that they are the dried beds of former open waters, the molecules of which, in the course of millions of years, have escaped into space because of the lower Martian gravity and earlier higher temperature. However, according to another hypothesis, the ancient oceans are now frozen and covered with solidified dust. This not-so-well-known idea cannot be ignored, because the possible existence of a subsurface ice table would explain some of the areographic features and increase the ecological potential of the dark surface areas; furthermore, it would stimulate speculations concerning the origin of life on proto-Mars and even of a possible subsurface habitat for life on present-day Mars.

A. Subsurface Ice Table as Ecologically Effective Background behind the Dark Surface Areas

It was Baumann [74] who, in 1909, advanced the *frozen ocean theory*. Along the same line, Suess in 1952 [75] stated that "substantial quantities of water may be buried under dust and never become volatile at the low temperatures of parts of the planet." Recently, this frozen ocean theory has been elaborated upon in greater detail by Davydov [76]. He theorizes that there might be a subsurface ice layer 500 meters thick in the equatorial regions and 2000 meters deep under the poles. Beneath this frozen conglomerate, or "cryosphere," water might be found in the liquid state due to an increase of temperature in the interior of Mars. And when cracks in the ice layer occur, caused by Marsquakes, water may reach the surface and produce localized giant clouds and white streaks of fog, lasting several days, as have been described by Lowell [2] and Slipher [77]. White spots "glittering like ice" have been observed in the equatorial regions by Saheki [78]. More probable than volcanic quakes, impacts by giant meteorites of asteroidal origin could be considered as the cause of craters and cracks [47].

In this connection, a hypothesis advanced by Dirac in 1937 [79] might have real significance concerning the mysterious "canals." It states that the gravitational constant has decreased during the life of the solar system and continues to decrease. This has led to an expansion of the Earth, causing "tension cracks" or fissures on land and at the bottom of the oceans, as recently described by Dicke (see Dicke and Peebles [80] and Jordan [81]. The splitting of the two giant original supercontinents, Gondwanaland and Laurasia, about one billion years ago into several secondary continents, now widely separated by a continental drift (Wegener), is attributed to this gravitational phenomenon.

It is logical to assume that on Mars, too, this gravitational decrease has caused similar effects, namely, volume expansion and tension cracks after it had cooled off at the end of its protoplanetary phase and had reached a temperature equilibrium. And meteoritic impacts should have produced fissures of tremendous dimensions in a crust of different layers. This might well have been the mechanism behind the scene of the dark spots called oases and the dark linear markings radiating from the dark spots over tremendous distances.

The existence of a subsurface ice and water table would be of great biological significance. For example, it would increase the humidity locally (in and around the meteoritic impact craters and fissures), making them ecologically more suitable for the growth of vegetation. Actually, it might be the soil's humidity and vegetation that make these areographic surface features visible in the first place to the Earth-based optical astronomy. It is interesting to note in this connection that oases, found within the dark areas, are surrounded by large, still darker regions. It is difficult to find an explanation other than widespread higher soil humidity. And, finally, a subsurface ice layer, or hydrocryosphere, would represent a hidden reservoir for continuously replacing water molecules that might have disappeared into space in the course of millions of years, as suggested by Barabashov [82]. Without this underground water source, the red planet would then be completely dry. This, of course, would exclude life on Mars completely.

How does the assumption of a hydrocryosphere conform with the close-up pictures of Mariner 4? One of their interpretations suggests that the "visible Martian surface is extremely old and that neither a dense atmosphere nor oceans have been present on the planet since the cratered surface was formed" [83]. Mars seemed to be more "moonlike" than "earthlike."

But, according to other interpreters [84], the surface is only about 300 to 500 million years old, and "the crater density on Mars no longer precludes the possibility that liquid water and a denser atmosphere were present on Mars during the first 3.5 billion years of its existence." The acceptance of this interpretation leads to interesting speculations. It might be that some 300 to 500 million years ago Mars, after it had lost most of its water into space, entered a permanent ice age. The remaining frozen ocean in the course of millions of years became covered by a deep layer of dust that became solidified and was subsequently bombarded by numerous asteroidal meteoroids; this could have started after the disruption of Planet X, the matrix planet of the asteroids, some 300 million years ago. And this might be the face of Mars of today [85, 85a].

Of interest concerning humidity are the hoarfrost-crowned craters in some of the Mariner 4 pictures and a white spot with a dark spot at one side in picture 14, which looks like a big cloud casting a shadow below. The Mars probe made some contribution to the hydroecologically interesting question of the altitude ranges. According to one analysis of the radio occulation measurements, the reddish area, named Electris, might be 5 km higher than the dark region, Mare Acidalium [86]. This, then, would confirm in a quantitative way the generally accepted opinion that the reddish areas are highlands, the continents of ancient times. The dark regions, then, are the lowlands covering the low-level remnants of the ancient and now frozen ocean. It is only logical to assume that the dark lowlands have a higher soil humidity because of the underground ice table and thus offer an ecologically more favorable substratum for the existence of a Martian surface biosphere. They are called "maria," but in the light of the frozen ocean theory they are entitled to this name only in a figurative sense; they are the image of the underground ice table projected to the surface by higher soil humidity and a resulting biosphere. This may be the conclusion that can be drawn from the frozen ice hypothesis concerning the dark areas and their permanent locations.

B. Martian Paleobiology

If we accept the occurrence of life on the Martian surface as sufficiently indicated by visual, photographic, spectroscopic, polarimetric observations, and theoretical reasoning, then we must go farther and theorize about its origin and evolution. In fact, a synopsis of the Martian life theories without a look into the past would be incomplete. If there is life on Mars, and since water must be regarded as the matrix environment of the origin of life on Earth, it is implied that Mars must have had oceans in ancient times.

Concerning the origin of life on Earth, the theory proposed by Urey [14], Oparin [87], and Haldane [88] is generally accepted, according to which, under the effect of ultraviolet solar radiation and/or lightning, organic material was produced in the primordial reducing atmosphere (consisting of H_2, CH_4, NH_3) or in the upper layers of the oceans. This process has been reproduced in the laboratory [89–91]. The resulting "nutrient broth" was the matrix material from which, during this "chemical evolution" [30], the first living cells originated. These, then, must be classified as heterotrophs living upon organic substances abiogenically produced. The following "organic evolution" led to the emergence of autotrophs of the chemosynthetic and photosynthetic types, and of advanced heterotrophs living on biogenically produced organic material. These were the primordial stages of life during the Archeozoicum and Proterozoidum on Earth, some $2\frac{1}{2}$ to 3 billion years ago.

It is not unreasonable to assume that life has developed on proto-Mars under similar conditions in a corresponding pattern. Unless open waters once were present, below a reducing protoatmosphere, it is difficult to imagine the origin of any living organisms on Mars. For this reason, the ocean theory discussed earlier gains significance. Its existence at one time in the past must be regarded as a *conditio sine quo non* for life on Mars. The evolution of life might never have exceeded a stage comparable with the terrestrial paleozoicum because of the low-level Martian ecology, or it might have flourished more luxuriantly in earlier times when the Martian atmosphere was denser and the temperature and humidity higher within the air–soil interface.

C. Subsurface Aquatic Paleobiosphere

If liquid water is found in substantial quantities below the surface of Mars, underneath a stratum of ice at depths of 0.5 km or more, it could be considered a potential habitat for living organisms [92]. Life could indeed be imagined there in terms of terrestrial hydroecology. The high hydrostatic pressure would not be a prohibiting factor for barophilic (pressure-tolerant) bacteria such as those found in the bottom sediments of the Pacific Ocean as deep as 10,000 meters (1000 atm pressure). On Mars, with its lower gravity, the pressure in the assumed water table, plus the pressure of the lithospheric layer above, would be well within the range of tolerance for terrestrial barophilic organisms.

The existence of organisms in such a hyperbaric, aphotic, aquatic environment with a temperature slightly above the melting point of ice is indeed conceivable, and their metabolism may be based on chemosynthesis. This could be an earlier paleobiological stage of life preserved in a more or less closed ecosystem. If so, the Martian biosphere would have two sections: one more highly developed, predominantly photosynthetic on the land surface, and the other a more primitive chemosynthetic type in the underground water table. The latter may present a chapter of the early paleological phase in the history book of Martian life.

These two habitats need not be isolated from each other. Cracks in the ice layer, produced occasionally by meteoritic impacts, might lead to intercontaminations between the upper and lower sections of the Martian biosphere. If this happens, photoautotrophs from the dark green surface areas might switch to chemosynthesis, a capability that some terrestrial photoautotrophs possess. Then the lower biospheric section, if it exists, could be considered a "semiclosed ecosystem" in comparison with the open ecosystem of the dark surface areas.

After this excursion into the Martian paleontology, we conclude this synopsis of the Martian life theories, which followed the line of realistic geoecological thinking. It is to some degree hypothetical and in some points even heretical in view of present areological knowledge. The supposition of life on the surface of Mars is supported by some convincing indications. The possibility of an underground water table as a second habitat for life must be considered a hypothesis with no evidence, at present.

V. The Search for Life with Automated and Manned Landers

In the search for extraterrestrial life, we are at present in the phase of theorization and laboratory simulation experimentation and testing of organisms under space conditions in artificial satellites [93]. But preparations are already underway for the experimental exploration of possible biota on the spot, i.e., on the neighboring celestial bodies [39, 94]. In the years ahead, automatic life-detecting devices on board unmanned landers will be sent to Mars for acquisition and analysis of soil samples and for transmitting the data to Earth. But the final and more comprehensive answer concerning a Martian biosphere may have to await a manned landing mission. Only pressure suited explorers, walking around on the surface, will be able to select diverse regions of the planet and analyze soils in a research laboratory. Only they will be able to take a deep look at rock formations in fissures and craters which might give us some information about the paleological evolution of life on Mars. If some day the question of extraterrestrial life is answered in a positive sense—and the answer may well first come from Mars—this will be *the* news in the recorded history of mankind. Moreover, it will extend the earth-related Cenozoicum, i.e., the recent geological era, into a universal spectrum, the Cosmozoicum.

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