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CURRENT PROBLEMS IN RESEARCH

Martian Biology

Accumulating evidence favors the theory of life on Mars, but we can expect surprises.

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The most plausible explanation of the markings on Mars suggests that they are living organisms, and the purpose of this article is to discuss them from this standpoint. But two other topics must also be considered. First, the environment of Mars and the markings themselves must be described. There is still much to be learned about both. Perhaps our most severe limitation is the seeing—the poor resolution in telescopic images of Mars, caused by our turbulent atmosphere. Mars appears blurred and distorted when viewed directly or when photographed, regardless of the size of the telescope. Second, although the biological theory best explains the markings, physical theories are not completely implausible. I will discuss them briefly.

The Planet Mars

In Table 1 are summarized some of the physical data relating to the planets of the solar system. Mars is smaller than the earth, with about two-fifths as much gravitational attraction at the surface. The day length is very nearly the same on Mars and on the earth, but the year is twice as long on Mars. Both have seasons, because of the tilt of their axes to the plane of the ecliptic, but Mars is closest to the sun (in its eliptical orbit) when the south pole is tilted toward the sun, and so summer is warmest and winter is coldest in the southern hemisphere. The intensity of the light reaching Mars averages about 43 percent of that reaching the earth (but then few earthly plants show increased photosynthesis as intensity increases above 20 to 40 percent of full sunlight).

Mars should be cooler than the earth because of its greater distance from the sun and because the thin Martian atmosphere would allow a great deal of heat to radiate to space at night. Figure 1 shows surface temperature measurements (*1*), as summarized by Gifford (*2*), which are typical (see, for example, *3–5*). In Gifford's figure the daily temperature changes on Mars are compared with those on the Gobi desert. The order of magnitude of temperature fluctuation is the same in both cases, but Mars is nearly 40°C cooler at all times. Since the earth revolves between Mars and the sun, we can never see midnight on Mars. Extrapolation of curves such as those in Fig. 1 indicates that night temperatures may drop to −70° or even −100°C. Temperatures are highest near the equator at noon, and dark areas may be 8°C warmer than light areas (*4*).

From the biological standpoint, the atmosphere is obviously important (*6*). Estimates for total atmospheric pressure are difficult to arrive at and somewhat unreliable. Nevertheless, de Vaucouleurs (*7*) summarizes a number of estimates, including his own, and arrives at a value of about 6 to 10 centimeters of mercury for the surface atmospheric pressure on Mars. This is about 0.10 atmosphere—a pressure that would be encountered approximately 10 to 11 miles above the surface of the earth (at twice the altitude of Mount Everest!). At 0.062 atmosphere human blood would boil at its temperature of 37°C (*8*).

So far, only carbon dioxide has been repeatedly detected (by spectrograph) in the Martian atmosphere (*3, 4, 9, 10*). The quantity of carbon dioxide above the surface of Mars has been estimated to be from two (*9*) to 13 times (*10*) that above the surface of the earth, and the higher value is probably the more nearly correct.

Careful spectrographic studies have failed to demonstrate either oxygen, ozone, or water vapor in the atmosphere of Mars (*11*). Estimates, based upon the assumption that the Martian blue haze (discussed below) consists of ice particles, place the amount of water vapor in the Martian atmosphere as low as 2 microns of precipitable moisture (*6, 12*), with a dew point of −90°C. Such a minute quantity of water vapor will probably not be detected by spectrographic methods until a measurement can be made from outside the earth's atmosphere (for example, from a satellite).

Nitrogen absorption lines occur in the ultraviolet part of the spectrum, which is filtered out by our ozone layer. Nevertheless, most authors assume that nitrogen accounts for the bulk of the Martian atmosphere. Argon is produced by the radioactive decay of a potassium isotope and doubtless occurs in the Martian atmosphere.

I shall briefly discuss three important atmospheric features: the blue haze, white clouds, and yellow clouds.

The blue haze. The surface features of Mars are visible when the planet is photographed in red light but usually not when the planet is photographed in blue light. There seems to be a haze with high light-scattering properties in the blue region of the spectrum. It can best be accounted for on the assumption that it consists of minute water ice crystals (*12*), although carbon dioxide ice and recently carbon or hydrocarbon

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Table 1. Environments of the planets.

Planet	Relative surface gravity	Period: Rotation	Period: Revolution	Inclination of axis to ecliptic (deg)	Approx. temp. (°C)	Mean relative energy from sun (per unit area)	Radiation striking surface	Atmosphere*: Water vapor (%)	Atmosphere*: Oxygen (%)	Atmosphere*: Carbon dioxide (%)	Atmosphere*: Other	Relative atmospheric pressure
Mercury	0.38	88 day	88 day		−234† +277‡	6.60	Complete solar spectrum	0	0	0	0	0
Venus	0.88	10–30 day(?)	224.7 day		77	1.90	?	<2	<2	>10,000	?	?
Earth	1.00	23^h56^m	365.3 day	23	−71 to +57	1.00	Most ultraviolet light filtered out	100	100	100	N, Ar, other	1.00
Mars	0.39	24^h37^m	687.0 day	25	−101 to +30	0.43	Ultraviolet sometimes penetrates	<1	<1	200	N, Ar§	~0.10
Outer planets‖												
Uranus	1.05			98								
Jupiter	2.65	$\sim 10^h$		3								
Neptune		$\sim 16^h$										
All			12–165 yr		−134 and below	0.04 and less	?				Methane, NH_4, H, He	?

*Expressed as a percentage of that occurring above the earth's surface. †Dark side. ‡Light side. §N and Ar inferred. ‖Pluto excluded.

smoke have been suggested (*13*). Occasionally the haze disappears on a continental or even planetary scale (if it consists of ice crystals, these must sublime). During this blue clearing, ultraviolet light would penetrate to the surface of the planet at intensities which would probably be lethal for the majority of our earthly organisms. An interesting feature of the blue clearing is that it seems to occur most frequently at opposition, when the sun, the earth, and Mars are nearly in a direct line (*14*). It would be extremely interesting to know if the position of the earth can thus influence the Martian climate; this apparent influence may be an illusion, as most observers are watching Mars only around the time of opposition.

White clouds. Sometimes white clouds can be seen, especially over the polar cap (*15*). These may be similar to earth clouds, although they probably always consist of ice crystals. There is some evidence that they produce rain on rare occasions (*16*).

Yellow clouds. Occasionally yellow clouds obscure certain portions of the planet, as in 1956, when nearly all of the markings were covered by an extensive yellow cloud formation during opposition (*15; 17*, p. 534; *18*). These clouds are usually thought to be a fine yellow dust (*19*). Markings on the planet may be temporarily tinged yellow after such a cloud has passed over, but within 1 to 2 weeks they are again visible.

A brilliant white cap (occasionally tinged yellow after a dust storm) usually covers the pole that is experiencing winter. The most prominent polar cap is usually the southern one (*20*) (Fig. 2). As spring comes in the southern hemisphere the cap begins to disappear and another one starts to form in the north, where autumn is beginning; this suggests a movement of material between the poles. It was long ago suggested that the polar caps might consist of solid carbon dioxide (dry ice), but spectrographic observations seem to indicate that they consist of frozen water instead (*9*). Most observers think they are very thin, like a layer of frost or perhaps occasionally like a light and fluffy snow. In 1956 the north pole was heavily covered by cloud formations, and when the clouds finally disappeared a brilliant polar cap could be seen (*15*). As the polar caps recede, portions of their edges may remain separated from the main cap for a time, apparently indicating an unevenness in topography (*21*). It has been estimated that plateau-like formations having an elevation of approximately 1000 meters would account for the observed irregularity in melting (*17*, p. 534; *18; 22*).

Apart from the markings, the surface in general has a yellowish-to-reddish tinge. The red color has often suggested the presence of iron oxides such as limonite (*17*, p. 343; *23*). Silicates, so common on earth, do not seem to be prevalent (*3*). There is some evidence that the surface of the planet is covered with a fine dust (*19*).

The markings as they appear in Figs. 2, 3, and 4 should be studied carefully. Note that they are most conspicuous in the southern hemisphere, and roughly triangular. The points of the inverted triangles extend over the equator into the northern hemisphere. It is possible to see a great deal more detail with the naked eye than can be photographed. The eye is able to catch slight details which appear only for brief instants when the atmospheric disturbances above the telescope are minimal. Thus, the sketched maps of Mars are always far more detailed than any single photograph. Yet virtually all of the features shown on the standard map have been photographed at one time or another.

Much of the argument and discussion center about the color of the Martian markings (*15; 17*, p. 534; *24–26*). From the vantage point of the earth the markings are of pastel shades which are difficult to describe. The colors are also variable from year to year, and the contrast between the color of a marking and that of the surrounding so-called deserts may tend to fool the eye. Generally, in winter the areas are relatively light colored, probably bluish-to-gray. As spring approaches, the color darkens (all observers seem to agree on this point). In some cases this darkening may occur with little change in hue, but often the colors in certain areas become brownish, reddish, black, or even a moss green. If one views a marking through a small hole, so that the surrounding deserts are eliminated from view, a distinct reddish tinge becomes noticeable, indicating that some of the substrate color is showing through the marking. It is very significant that the color change begins in the spring next to the polar cap and progresses toward the equator, indicating a close dependence of the color change upon melting of the polar cap. In the case of spring in the southern hemisphere the color change continues over the equator into the northern hemisphere.

The areas often change shape from one opposition to another. Mars has been watched with fairly good telescopes for about a century, and virtually all of the markings shown in the map in Fig. 4 have manifested, at one time or another, this sort of change (*17*, p. 534). Occasionally new areas appear, or well-known ones vanish and reappear. Hellas, for example, darkened in 1954 but was bright again in 1956 (*17*, p. 534), and in 1954 an area about the size of Texas appeared in what had previously been open desert (latitude 20°, longitude 240°).

Since 1877, when Shaparelli first described the canals, many observers have discussed the network of lines criss-crossing the deserts and even extending across the dark areas themselves. They are difficult to see, but occasionally certain of the canals have been photographed. One school of thought holds that they are really not straight lines at all, but only scattered points which blend into an apparent straight line because of the poor resolution (*17*, p. 534). But whatever the canals may be, the color changes also occur from pole to equator along them. No one thinks of the canals as open waterways, and most of them must be at least 10 to 50 miles wide in order to be seen with our telescopes. Lowell (*27*) thought they might be farms along small or underground waterways.

It is interesting to note that the canals never seem to terminate in the desert areas without connecting to something, such as another dark area. Often two canals will intersect, and their point of intersection is marked by a slight expansion in their color. These spots at the canal intersections have been called oases.

Theories Concerning the Markings

Various theories have been proposed to explain the markings.

Inorganic salts which change color with changes in humidity. This theory was put forth early in this century by the Swedish chemist Arrhenius (*28*). Known chemicals will not account for the course of events on Mars. Nevertheless, lack of knowledge on our part does not constitute disproof of a theory.

Volcanism. A few years ago it was suggested by McLaughlin (*29*) that the markings on Mars might consist of volcanic ash produced by volcanoes located perhaps at the apex of the triangular features. The shapes of the areas were explained as wind patterns, and the color changes as wind disturbances of the ash. There is some evidence to indicate that volcanic activity has occurred or is occurring on Mars (discussed in a later section). Kuiper (*15*) suggests that the areas may consist of lava fields, but both he and McLaughlin now consider the possibility that vegetation of some sort may be present on these lava or ash fields. The volcanism theory would require more water in the atmosphere than is believed to be present and it seems inconsistent with the detailed color changes and other phenomena, but it is probably the best physical theory available.

Oxides of nitrogen. There is some evidence for certain nitrous oxides in the Martian atmosphere (*30*). These compounds may occur as solids, liquids, or gases of various colors, including brown, yellow, bluish white, a greenish shade, and the many shades which may be obtained by mixing these. Kiess, Karrer, and Kiess (*30*) proposed in early 1960 that this complicated chemistry might account for virtually all the Martian phenomena. According to this theory the polar cap consists of bluish white nitrogen tetroxide. Brown clouds of nitrogen dioxide gas, produced as the polar cap melts, flow through depressions on the planet (the large dark areas) and canyons or earthquake cracks (the canals). The theory is an attractive one. The authors have accounted for nearly everything that

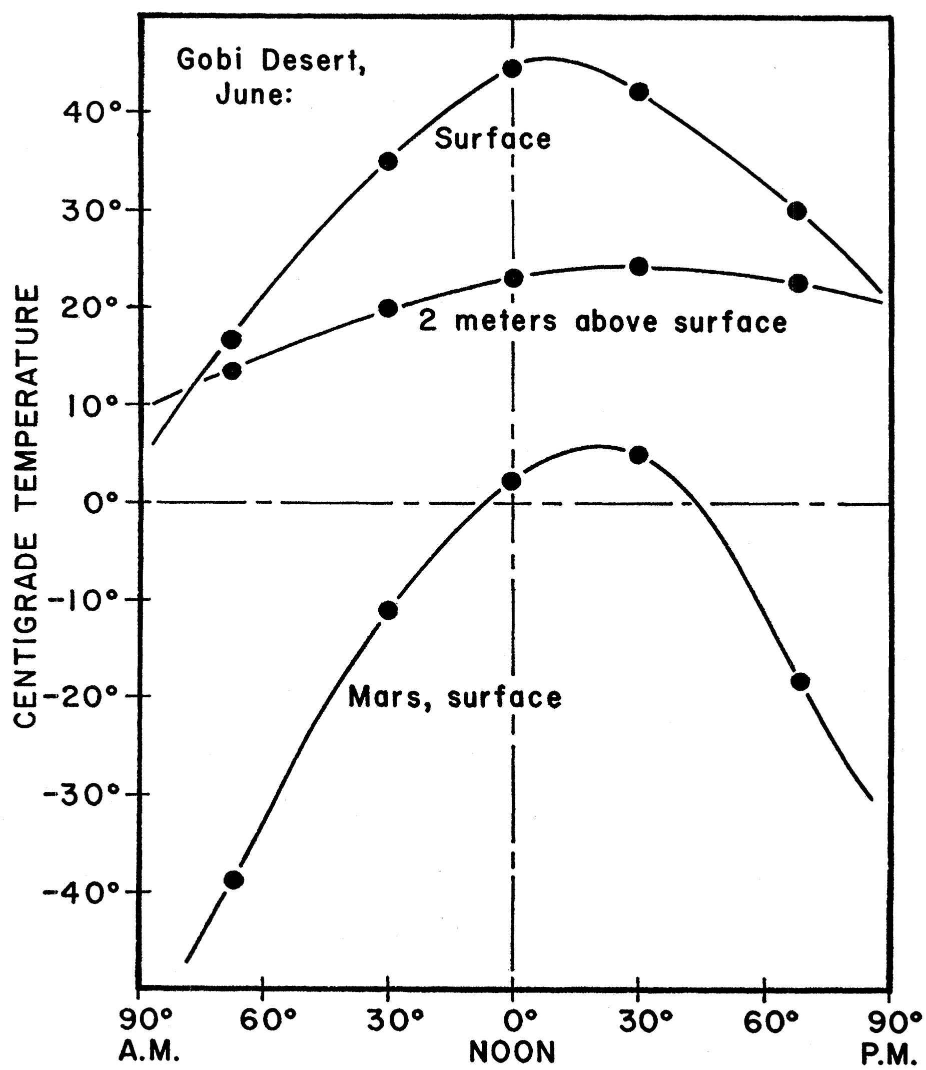

Fig. 1. Average temperatures on Mars (at the equator) compared with temperatures on the Gobi Desert. The abscissa represents degrees of longitude east or west of the noon meridian. Each point for Mars is an average of 31 to 84 measurements made between 1926 and 1943 at the Lowell Observatory by Lampland and summarized by Gifford (*2*). Of course many individual measurements were higher than the averages shown, and the known systematic errors in the methods might produce values which are too low. Thus, the curve may be thought of as an average lower limit.

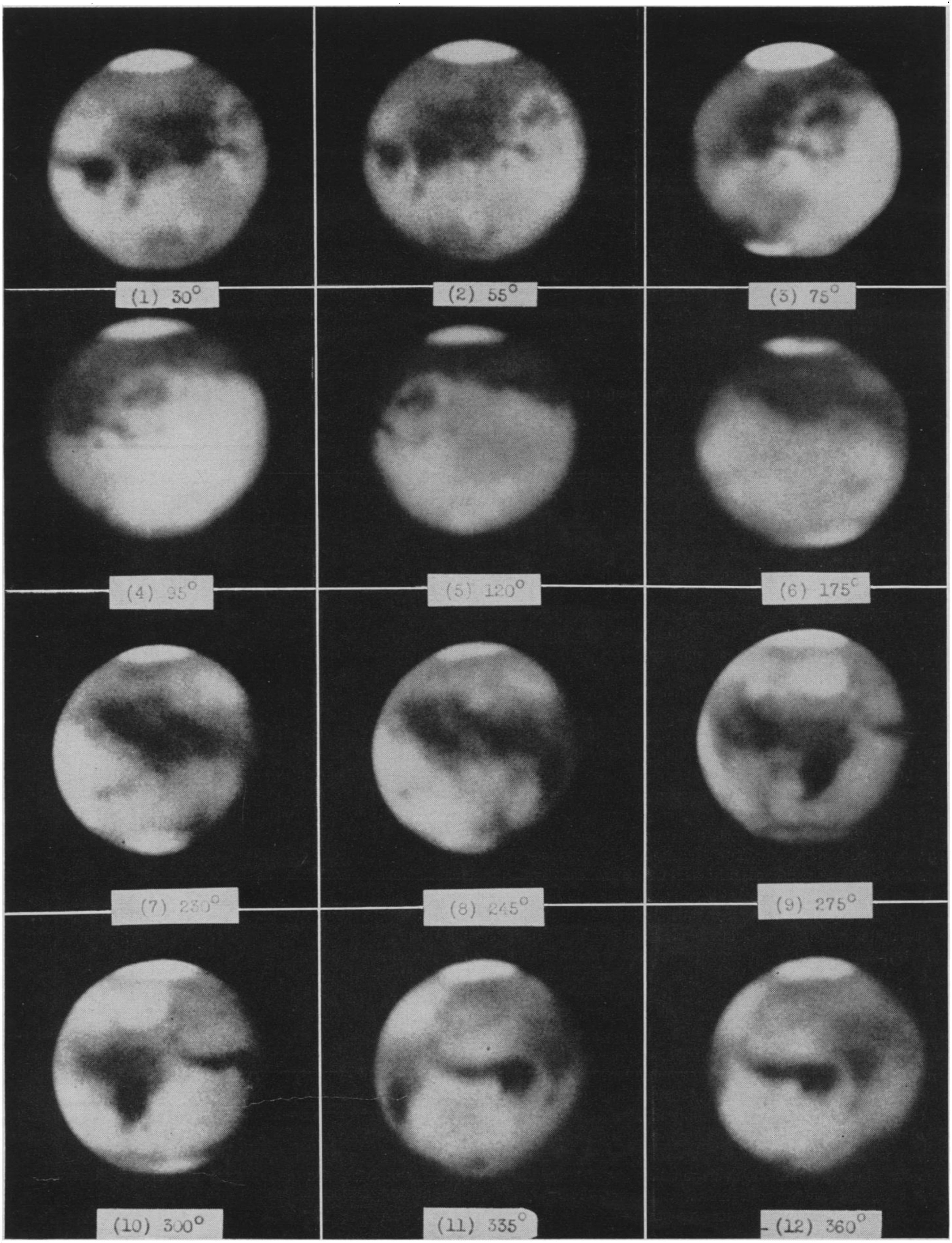

Fig. 2. The markings on Mars as the planet rotates (compare the specific markings with the map, Fig. 4). [Photographs taken in 1939 by E. C. Slipher, Lowell Observatory]

troubles the mind of the observer of Mars. Nevertheless the objections which have been raised seem fatal to the theory. Thermodynamics fails to agree with the theory (*31*), and even worse, the various postulated forms of nitrogen oxides should have certain quite distinct absorption bands, which do not appear in the observed spectra (*32*).

Living organisms. According to the obvious and most discussed theory, the Martian dark areas and the associated canals represent living organisms which change color in response to increasing temperature and slight amounts of water made available by the melting (or the subliming) of the polar cap. I will discuss five arguments in support of this idea. Only one of these (that based on the evidence of Sinton's bands) is at all direct, and all the phenomena are subject to alternative explanations. Interpretation number 5, the assumption of intelligence, is especially debatable. Nevertheless, the five lead to the conclusion that there is a high probability of life on Mars.

1) The changes in color, size, and shape of the markings fit the living-organism theory most readily. These changes in color and size are relatively extensive and spectacular, and if the markings consist of vegetation of some sort, the cover must be fairly complete. Rocket photographs of our western deserts, for example, show a light-brownish expanse, devoid of much detail, but an observer on the ground sees an abundance of living organisms. Only the fairly heavy cover of our forest and grass areas appears really green on such rocket photographs. This, and the changes in color and size, seem to indicate a very flourishing life form on Mars, and not the barely existing lower plant forms so often suggested.

2) About a decade ago Opik (*33*), an Estonian astronomer, pointed out some interesting evidence in support of the living-organism theory. Since yellow dust clouds move rather frequently across the planet, one might expect that anything unable to grow through or shake off the deposited dust might soon be obscured, and that the planet would appear uniformly yellowish. Kuiper (*15*) has suggested that fields of glassy lava might be readily blown free of the dust; but in that case wouldn't the dust settle in depressions, allowing only points of lava to appear above the dust layer and essentially obliterating the lava fields?

3) Dollfuss (*17*, p. 343; *24*) interprets his polarimeter readings to mean that the surface of the dark areas is covered in winter by particles of very small diameter which become larger and change color with the approach of spring. He suggests that these might be microorganisms. The actual curves presented show little detail, however, and such a narrow interpretation hardly seems justified.

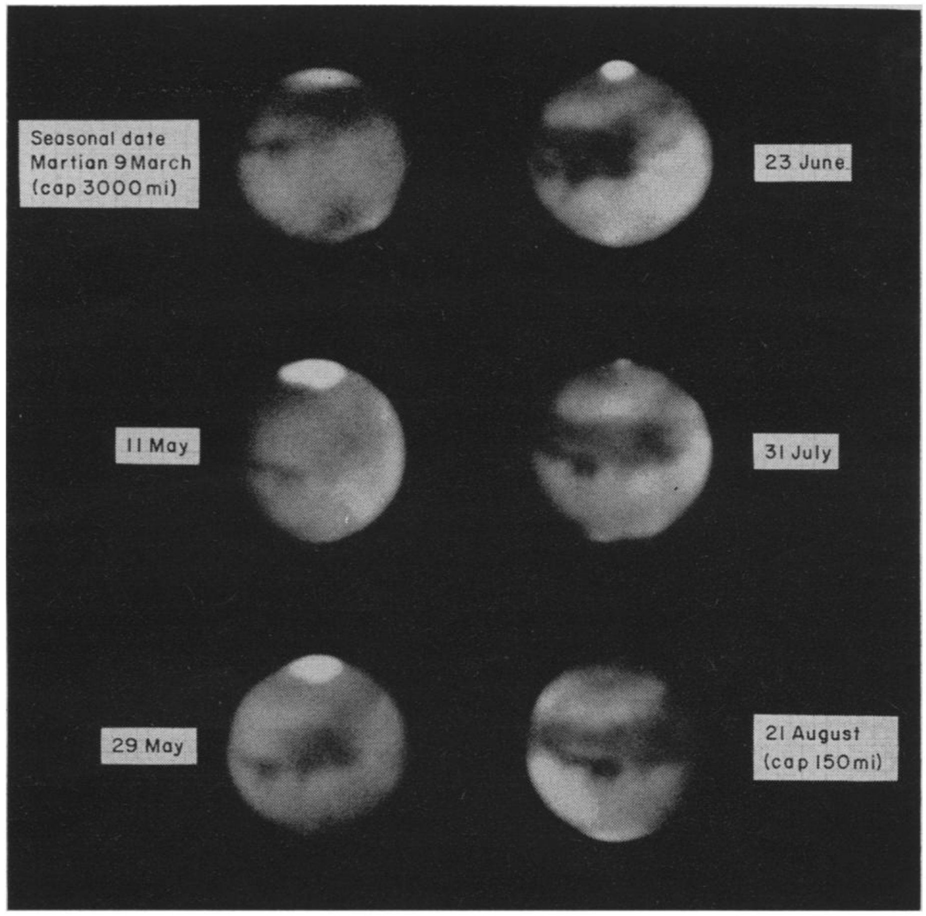

Fig. 3. Some seasonal changes on Mars from the Martian seasonal dates, 9 March to 21 August. Note the gradual decrease in the polar cap and the increase in intensity of dark markings in the tropics. [E. C. Slipher, Lowell Observatory]

4) Recently Sinton (*34*) has obtained absorption bands in the infrared which are interpreted as evidence for carbon-hydrogen bonds, aldehydes (*35*), and perhaps carbohydrates. If the interpretation is correct, this would constitute by far the most positive and direct evidence of the existence of vegetation on Mars. Since the bands appear in the reflection spectra of the dark areas and not in the spectra of the surrounding deserts, the evidence is particularly striking. Of course, organic molecules may be lying around on a sterile world, but this hardly seems likely in view of the color changes and other observations (*25*).

5) Certain features about Mars are most easily understood on the assumption that they are the product of intelligent beings. Other interpretations are always possible, but we should not arbitrarily close our minds to the implications of some striking observations. The canals, of course, have long been interpreted as the visible evidences of a Martian irrigation system designed to make the best use of water produced by the melting polar caps (*27*). In recent years it has been suggested that the moons of Mars may be artificial (*36*). The two satellites rotate in nearly circular, equatorial orbits, and in this respect they differ from the natural satellites of any other planets in the solar system. They are close to the planet (Phobos is about 3700 miles above the surface; Deimos, about 12,100 miles) and are very small. If Deimos and Phobos reflect no more light than our moon, then they are probably 5 and 10 miles, respectively, in diameter. If they are more reflective than our moon, then they are smaller. One of them accelerates in a peculiar way, best explained by assuming that it is a hollow sphere. Most interesting are the circumstances relating to their discovery. In 1862, at the best opposi-

tion of the 19th century, a search for satellites around Mars ended in failure, but in 1877, at the next close opposition, the two satellites were detected by Asaph Hall. Should we attribute the failure of 1862 to imperfections in the existing telescopes, or may we imagine that the satellites were launched into orbit between 1862 and 1877? On several occasions observers of Mars have noticed a bright spot of light lasting about 5 minutes (*36, 37*). Sometimes this has been followed by a rather distinctive white cloud, which grew in size and faded after about an hour. Was this volcanic activity, or are the Martians now engaged in debates about long-term effects of nuclear fallout?

Known Life Forms as Potential Inhabitants

At this stage of our ignorance it is unsafe to draw any sort of positive conclusion. No one of these five arguments excludes a counterargument. It is, nevertheless, quite likely that there is life on Mars, and the environment and markings allow us to set up certain criteria which may be used in evaluating known life forms as potential inhabitants of Mars—inhabitants which might be responsible for the markings.

1) The suspected organisms must be visible or must form visible colonies which cover the ground rather extensively.

2) The suspected organisms must account for the color (the light-reflecting properties in general) and the observed color changes. The color changes should take place in response to increases in temperature and atmospheric moisture.

3) The suspected organisms must account for the observed changes in size and shape of the Martian areas—that is, they must migrate or grow with some rapidity, and they should be able to reemerge from a covering of yellow dust.

4) The suspected organisms must exhibit these various responses within the Martian environment, which is characterized by low temperature and great diurnal fluctuations in temperature—an extremely thin atmosphere, containing a considerable amount of carbon dioxide but only traces of oxygen or water, and occasionally penetrated by ultraviolet light.

5) The suspected organisms must conform to certain fundamental principles of ecology, such as the cycling of elements. A saprophitic fungus, for example, could not alone account for the markings on Mars since such a fungus must derive its energy nutrition from some other organism. Anaerobic organisms by themselves could not account for the markings since they are unable to break down carbon compounds to the elemental carbon dioxide, water, and minerals. All of the available carbon would soon be tied up in organic compounds, causing the cycles of nature to grind to a halt.

It is amazing how widespread life on earth actually is. Bacteria will grow and multiply in the sands of the desert. Certain algae and fungi survive the extremely hot, dry, salty sands of Death Valley (*38*). Some organisms will grow at the extremely high temperatures of hot springs, others, at the low temperature of snow (an example is the red-colored alga that grows in mountain snowbanks). Organisms live in the Great Salt Lake and the Dead Sea, and some organisms have been found in tanks of gasoline and even in phenol! The strange life forms found at the bottom of our deep oceans are a most impressive testimony to the adaptability and tenacity of life. Yet none of the organisms mentioned so far would be likely to form visible colonies or account for the changes in color or size or shape of the markings. They only suggest that something might be expected to meet the fourth criterion.

Animals in general fail to meet the foregoing criteria in one way or another. They could hardly be expected to form colonies visible from the earth, but animals as we know them must feed on some other form of life—ultimately on plants, which might be visible. Most higher plants with associated decay bacteria would quite adequately meet all of the criteria except the fourth one, that relative to the Martian environment. Higher plants universally require oxygen and a considerable amount of water, and most of them would be unable to survive the low Martian temperatures (although certain arctic and alpine plants might manage to do so).

Most lower life forms, including mosses, algae, and various other microorganisms, would fail to form colonies visible from the earth, and they require considerable quantities of liquid water for rapid growth. The lichens, as often suggested, might survive the Martian conditions. These extremely hardy organisms grow pressed against the surfaces of rocks in the Arctic, on the alpine tundra, in the desert, and even in Antarctica. Thus, they seem to meet the fourth criterion better than any other known organism. Yet a close examination shows that they fail rather dismally to meet the other criteria (*39*). Since they show virtually no seasonal change in color, they could hardly account for the one observation most suggestive of life. Furthermore, they are extremely slow-growing, their growth increment often being measurable in millimeters per year. Even on the relatively wet arctic tundras where they "flourish" it may take them as long as 25 years to return after they have been removed by caribou. Their shape is such that they would not readily emerge from a covering of dust, nor would they form colonies visible from the earth if water is limiting. A great many of them are very sensitive to low levels of oxygen. And the idea that lichens as a taxonomic entity are present on Mars is quite untenable unless one imagines that they were transplanted there from the earth, since the lichen is itself a complex double organism embodying a symbiotic relationship between an alga and a fungus. The fungus could only have evolved after rather advanced life forms had made their appearance, since it is parasitic or saprophytic with respect to such life forms. Thus, the presence of lichens implies, in an evolutionary sense, the presence of a great many other, much more complex, life forms.

So we must conclude that the presence of unmodified earthly organisms could not account for the markings on Mars. Yet the picture of Mars is still most easily understood if we assume the presence of life there. At this point there is nothing left to do but speculate.

What Can We Expect?

Can we mentally modify the organisms of earth in such a way that they would meet the criteria? The relatively new science of physiological plant ecology, which considers plant function in relation to the plant's environment, gives us a few clues, and, of course, our understanding of biochemistry is also very pertinent. At the outset we should note that it is easier to modify higher plants mentally so that they will meet the criteria than it is to make the often discussed lichens meet these criteria. If higher plants could live despite the near-total lack of water and oxygen, the low temperature, and the high ultraviolet light, then they would at least be

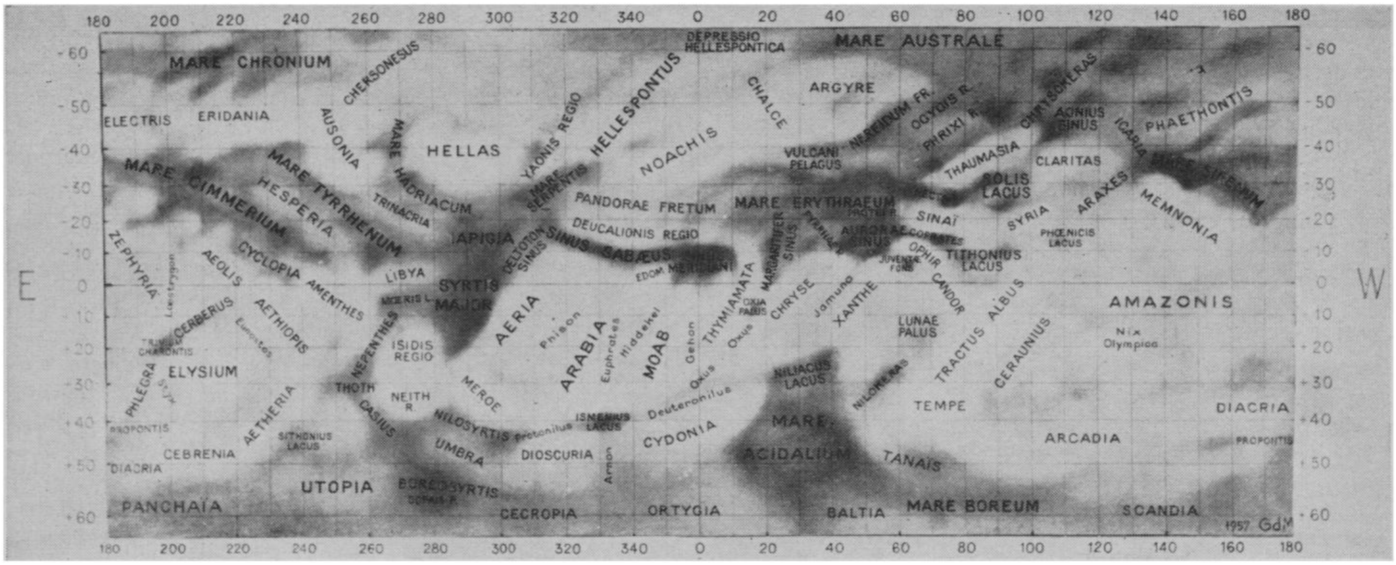

Fig. 4. Nomenclature for Mars as adopted by the International Astronomical Union in 1958. [Map prepared primarily by G. de Mouttoni and made available for publication by A. Dollfus, Observatoire de Paris]

capable of growing and propagating at sufficient speeds to account for the observed phenomena. Lichens, on the other hand, would have to be modified so extensively to account for these phenomena that they would no longer resemble lichens at all.

Probably ultraviolet light is the least serious of the adverse environmental conditions to be encountered on Mars. We would only have to add some sort of shielding pigments to our Martian organism to avoid this difficulty [pigments such as are found in certain fungi in Death Valley which withstand ultraviolet light and high gamma irradiation, an unknown quantity on Mars (*38*)]. The color studies of Martian markings do indicate that the pigment systems are unique, unlike those of any of our plants.

Modifications of plants to fit them for the extreme temperature conditions of Mars are also relatively simple to imagine. Heat transfer between the plant and its environment has been studied rather intensively, especially in Germany (*40*), and the results of this study provide us with some interesting points of departure. Because of the very thin atmosphere of Mars, heat transfer by convection and conduction would be relatively insignificant, and transfer of latent heat by evaporation would be negligible because of the small amount of water. Thus, anything on the surface of Mars is essentially in a radiation environment. Warming during the day is due to incoming radiation (as on the earth), and at night cooling occurs largely by radiation through the ozoneless, waterless, thin atmosphere into space. Only the carbon dioxide would tend to retard this radiation into space.

Thus, any plant adaptation that tended to increase the efficiency of radiant-heat absorption during the day and decrease the efficiency of radiation into space at night would be in the organism's favor. Fast warming during the day would be facilitated by pigment systems which tended to make the organism an efficient black-body absorber (*41*). Pigments which are black to ultraviolet, visible, and infrared radiation would be most efficient. The summer darkening and the general grayness of the Martian markings, as well as a low reflectivity in the infrared, might be considered deviations from this blackness.

The Martian organisms should present a broad, flat surface to sunlight during the day. Because of the low convection and conduction, a thin organ such as a leaf seems to be ideally suited in this respect. If this leaf could roll up into a small cylinder at night (a phenomenon not without precedent on earth), this would cut down night-time heat loss by radiation. A change of color at night (toward white) would also help, and color-changing organisms are not unknown on the earth.

The temperatures at night drop so low that no cold-blooded organism could keep from freezing, despite such adaptations. Nor would the presence of freezing-point-depressing solutes in the protoplasm be likely to provide an answer. It is simplest to imagine that the plants freeze every night and thaw out the next day and are not hurt by this. Again we have an abundance of earthly precedents. The lichen is a good example, as are many mosses and other lower life forms which withstand severe freezing [in some experiments they have been taken close to absolute zero (*42*)]. Even certain higher plants, such as those found above timberline in high mountains, withstand freezing (*43*). Most of these can tolerate the lowest temperatures only in the winter, when they are metabolically inactive, but some can stand freezing even at the height of the growing season. Apparently the plants simply freeze up solid and then resume their metabolic activity when they thaw out. By such a procedure Martian organisms could undoubtedly conserve a good deal of energy, since presumably they would not burn up their reserve food supplies while in the frozen state every night.

Water is extremely important for earthly organisms, and the color change in response to melting of the Martian polar cap seems to indicate that this is the case on Mars as well. A surface flow of liquid water from the polar cap is out of the question, since such water would freeze at night and evaporate in the thin atmosphere [there is reason to believe that liquid water does wet the soil at the edge of the melting polar cap (*7*)]. Water could move through pipes created by intelligent beings, but we would like to see this first-hand to believe it. The alternative suggestion is that the plants are responding to a slight increase in humidity of the atmosphere. The actual increase must be so slight that the response, to result in visible color change, would be quite surprising, although perhaps not out of the question. We begin to wonder how important water may be in Martian biochemistry. If water acts as a primary solvent or reaction medium, as it does on earth, the problem is indeed a serious one. The amount of water has been calculated on the basis of the size of the polar caps and the minute quantities of water vapor in the atmosphere. Such calculations seem to indicate that the amount of water available for organisms is so slight that the organisms can be only a fraction of a millimeter thick (*9*). One wonders, however, whether most of the water might not be tied up in the bodies of the living organisms and thus not available for the formation of the polar cap. (Water would also be tied up in the ice crystals of the blue haze, but this would probably not be available for plants.) I have wondered if water on Mars might not act more like a vitamin than like a primary solvent (*44*). A certain amount of hydrogen and oxygen would be supplied for essential reactions, but Martian biochemistry might not depend upon these elements as extensively as our own does.

Whether water is a primary solvent or a "vitamin," the question of water loss by the Martian organisms is an important one. The very shape of a herbaceous plant is dependent upon the water, as becomes evident when it wilts. Indeed, plants on earth are primarily conduits for water flow from the soil to the atmosphere. Surely this cannot be the case on Mars. There must be some unique adaptation which severely restricts the loss of water from Martian organisms. Such a mechanism is difficult to visualize. Our plants lose water because they must absorb carbon dioxide. The stomates, which allow a diffusion inward of carbon dioxide, allow an outward diffusion of water vapor. Since Martian organisms would undoubtedly require carbon dioxide as a carbon source, they would be faced with the same problem. We now have a model for the solution for this problem. Certain compounds, such as hexadecanol, may be spread on lakes in a monomolecular layer, preventing (or restricting) the evaporation of water, while oxygen and other gases continue to pass through. It has been suggested that a plant might absorb such compounds, have all its wet surfaces coated by them, and thereby restrict its water loss while still carrying out the necessary transfer of gases. Experiments designed to test this effect failed (*45*), but the model is there. We may imagine that the Martian plants contain the right

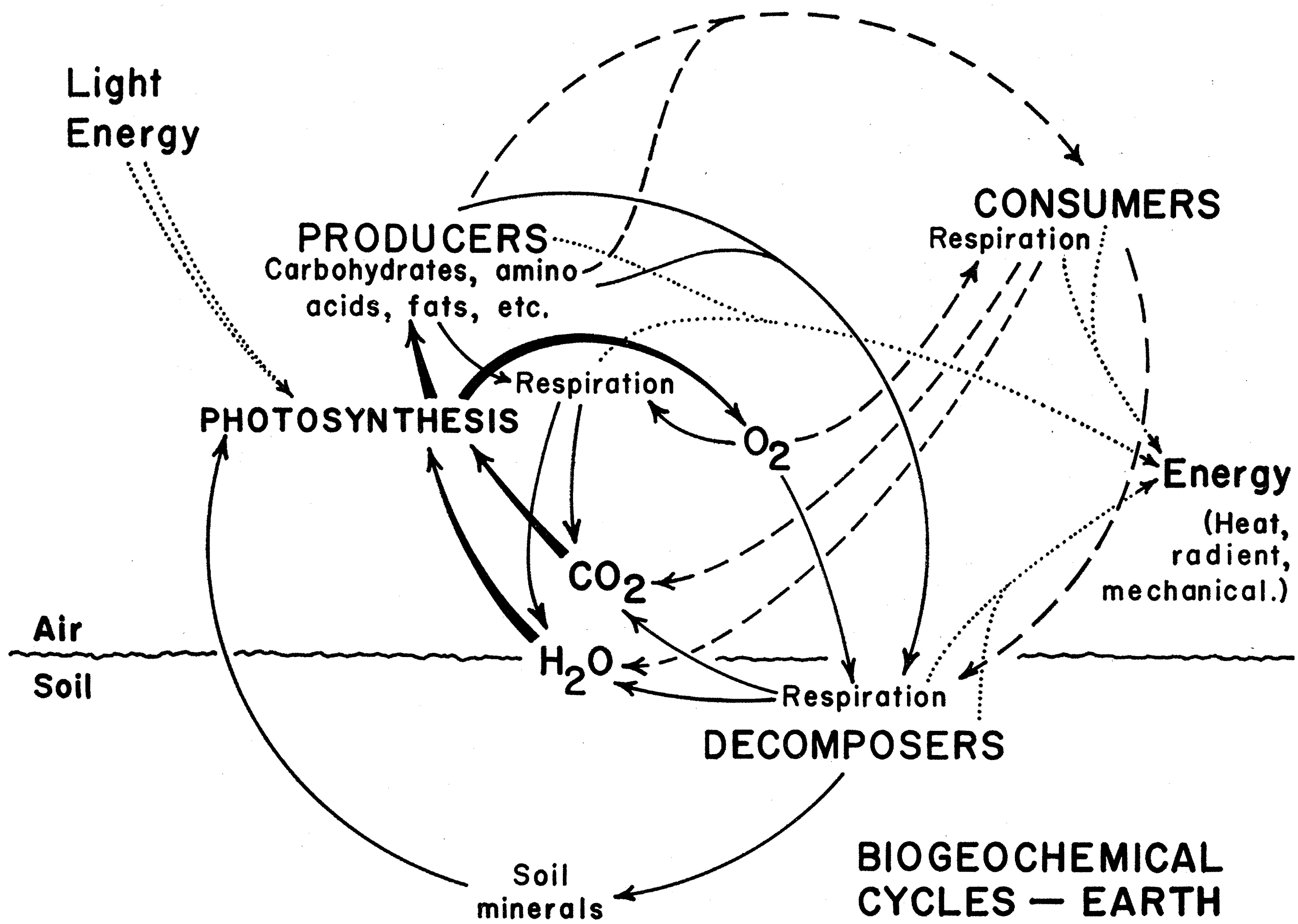

Fig. 5. Biogeochemical cycles on earth. Cycles of carbon, oxygen, hydrogen, soil minerals, and energy through the living organisms of the earth's biotic communities are indicated (nonbiological transformations are not shown). Solid lines show essential transformations between producers and decomposers. Broken lines indicate that consumers are not theoretically essential to a cycling of elements. Dotted lines show energy transfer from input as light energy to expenditure. Forked lines indicate that not all energy is lost through respiratory processes, but that some may enter the external environment via other metabolic and physical functions of the organism. Producers on earth are the photosynthesizers—the chlorophyl-containing plants. Consumers include the animals and many parasitic and saprophytic plants. Decomposers are primarily microorganisms, although it is sometimes technically difficult to draw a line between them and certain consumers. Water is indicated at the soil-air boundary because it usually enters metabolic reactions by first being taken up through plant-root systems.

compound to allow them to retain their water while absorbing carbon dioxide from the atmosphere.

Probably the most serious problem of all concerns the virtual lack of oxygen in the Martian atmosphere. Our whole biology is based upon the following reaction:

$$CO_2 + H_2O + \text{energy} \underset{\text{respiration}}{\overset{\text{photosynthesis}}{\rightleftharpoons}} (CH_2O) + O_2$$

The equation implies that if photosynthesis is occurring there must be oxygen in the atmosphere. Actually, all of the oxygen presently in the earth's atmosphere could have been produced by photosynthesis in a few thousand years. Yet on Mars the oxygen appears to be tied up in iron compounds on the deserts (*17*, p. 343; *23*). How can life proceed if oxygen produced by photosynthesis is immediately tied up and made unavailable for future use in respiration? Probably this is the most difficult of the dilemmas in our speculations about life on Mars.

Two solutions to this dilemma which have been proposed in the past seem to be quite inadequate. The idea of anaerobic respiration fails to meet the ecological criterion. Strughold (*8*) has suggested that Martian plants have an internal atmosphere in which oxygen produced by photosynthesis is captured and later used for respiration. But how could an organism take up carbon dioxide and not lose another gas, such as oxygen? And as in the case of anaerobic respiration, life would move in the direction of continual removal of carbon dioxide, with no replacement through the normal decay processes.

Only one proposed solution seems at all tenable, and this perhaps seems so because we know relatively little about such things and fail to recognize its shortcoming. The idea is that the basic biochemical mechanisms of Martian life are different from those of earthly organisms. The reaction given earlier can be radically simplified to a reaction showing only the transfer of electrons between carbon and oxygen:

$$C \underset{\substack{e^- \\ \text{storage of energy}}}{\overset{\substack{\text{release of energy} \\ e^-}}{\rightleftharpoons}} O$$

Obviously, the reaction can be further simplified as follows:

$$X \underset{\substack{e^- \\ \text{storage of energy}}}{\overset{\substack{\text{release of energy} \\ e^-}}{\rightleftharpoons}} Y$$

Here X and Y must be atoms which

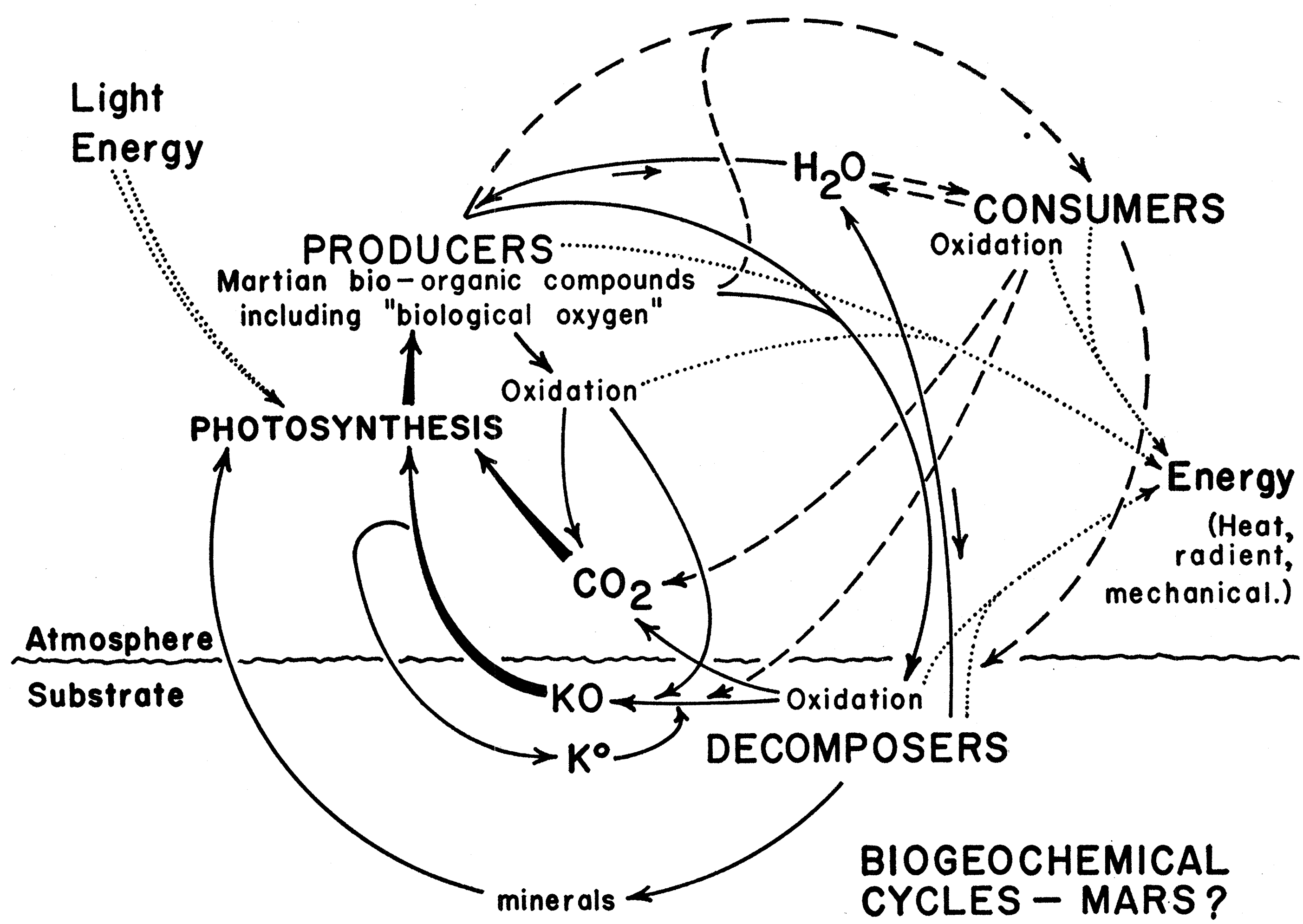

Fig. 6. Biogeochemical cycles as they might occur on Mars. An attempt is made in this figure to apply the balances shown in Fig. 5 to the Martian situation by keeping free oxygen out of the atmosphere and restricting water to the atmosphere. KO represents some compound of oxygen occurring in the substrate. K^o represents the free form of the K in KO, or K combined with something besides oxygen. "Biological oxygen" implies that the energy received in the form of light is transferred to the chemical energy of the Martian bio-organic compounds and to oxygen in some nongaseous form. Thus, it may later be combined with bio-organic compounds and K^o to produce KO and CO_2, releasing energy which might be used in life processes. "Biological oxygen" would thus be transferred from producer to consumer or decomposer as part of food. Such a scheme has many obvious deficiencies, and other schemes might be proposed (such as substituting nitrogen for the oxygen of Fig. 5), but the diagram indicates some of the problems and one possible approach to their solution.

differ from each other in such a way that the energy transfer involved is significant, but of course nearly any chemical reaction will involve such a transfer of energy. It is possible to imagine, for example, that the oxygen might be replaced by nitrogen with its many oxidation states. Although the energy-transfer system would be somewhat less efficient, the concept is helpful.

According to an alternative suggestion the Martian organisms may split off oxygen from iron oxides in the desert soils in a manner analogous to the way in which oxygen is split from water through photosynthesis in terrestrial plants (see Fig. 5). The oxygen would then be used in the organism's metabolism, and the decay process might involve a direct return to the original combinations with iron. This idea is shown schematically in Fig. 6.

Conclusion

Of all the proposals put forth to account for the observed Martian phenomena, the idea of life on Mars seems to be the most tenable. And if this idea is accepted, we are immediately drawn to the conclusion that this life is a very well-adapted and flourishing one—not the struggle for existence so often suggested in light of the obvious difficulties earthly organisms would have in living on Mars. The suggested criteria seem to eliminate all the known life forms, but of all these forms, a higher plant would require the least modification in order to meet the criteria. The basic shape of the leaf of a higher plant seems suited to conditions on Mars, but the lower gravity might well result in some interesting modifications in morphology. Some life forms on Mars might resemble our own higher plants, but we should be prepared to encounter some interesting surprises in biochemistry.

In light of the thriving nature of the Martian organisms, we should expect to see the operation of many principles of dynamic ecology—among them, surely, food chains and elemental cycles. A succession in the development of life forms must occur (was the new area in 1954 an example of plant succession in the desert or of an organized reclamation project?).

What about intelligence? If in place of struggling lichens we assume a thriving vegetational cover, then it is easy to add other members of the biotic community. If plantlike organisms have solved the problem of growth in the Martian environment so well, one might surely expect to find mobile forms comparable to our animals that feed on plants. And from there it is but one more step (granted, a big one) to intelligent beings. In view of the evidence, we should at least try to keep our minds open so that we could survive the initial shock of encountering them.

This has implications for our present program of space exploration. In the first place, we need improved observational data of Mars. A manned landing could solve all the problems posed in this article (*46*), but even telescopic observations from a satellite, especially one orbiting Mars, could provide us with extremely valuable data. Any such data will tell us much more about the planet and its possible inhabitants than years of research in which earthly organisms are grown in artificial environments "simulating" conditions on Mars. Such research might tell us about the physiology of these organisms, but it is difficult to see how it can tell us much about Mars. In the second place, the remote possibility that Mars is the abode of intelligent beings should make us think very carefully before we drop elaborate robots on Mars to look for signs of life—machines that reach out, suck in, pulverize, and analyze samples from the Martian surface. If there is *intelligent* life, the telemetered data received from the robot might be difficult to interpret! At least I can imagine how I might react if such an apparatus landed in my back yard and started grabbing for my apple tree, the cat, and maybe me!

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