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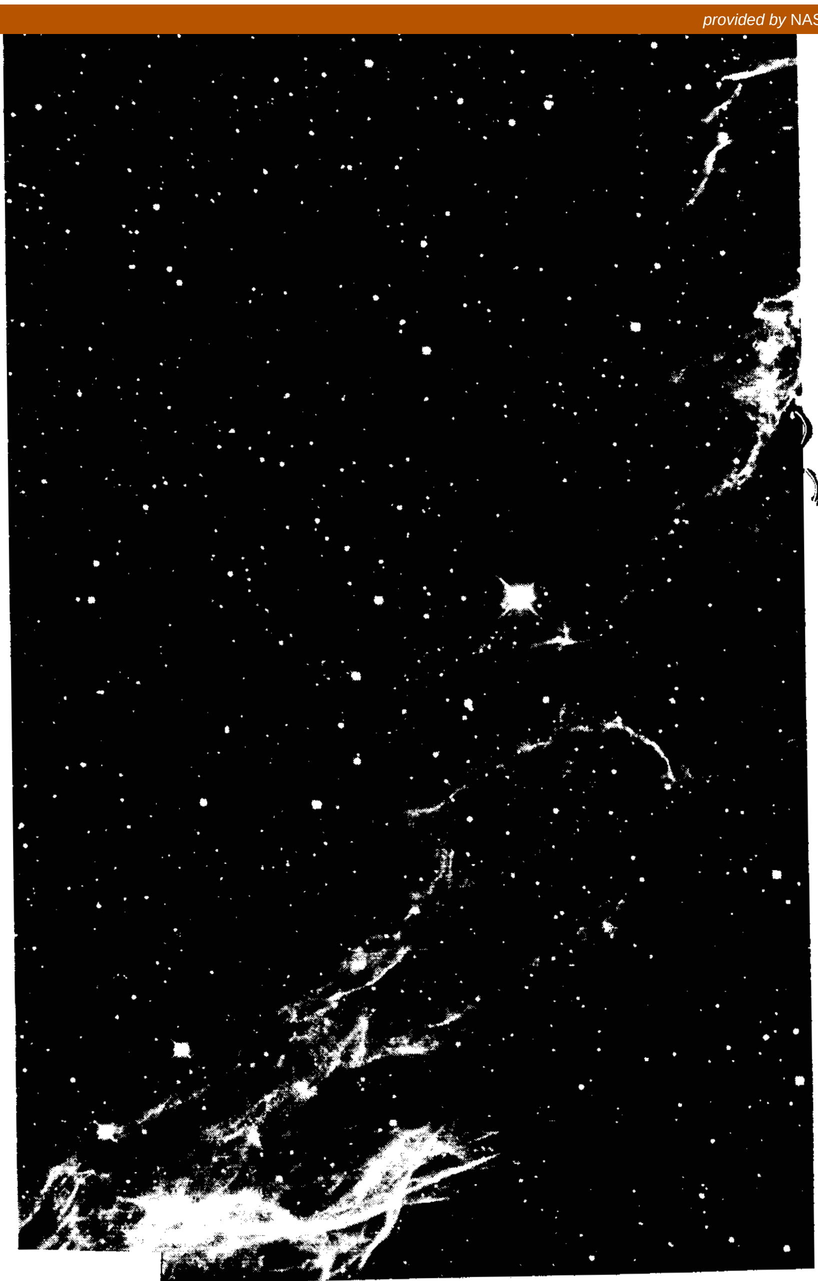

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# MISSION REQUIREMENTS FOR EXOBIOLOGICAL MEASUREMENTS ON VENUS

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# MISSION REQUIREMENTS FOR EXOBIOLOGICAL MEASUREMENTS ON VENUS

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# SUMMARY

For life to persist on the Earth there are certain fundamental requirements which include liquid water, an atmosphere containing oxygen and carbon dioxide, temperatures between about 0°C and 80°C, pressures between some 0.5 and 1000 atm, sources of food as organic compounds or carbon dioxide, and an energy source such as sunlight, heat or chemical energy. In addition it is thought that a methane-ammonia or perhaps an HCN environment must have been available for the development of the first single cells, and any changes in the environment should have been slow enough to sustain life as it increases in complexity. An examination of conditions on Venus indicates that life could survive there at least in localized biotic zones on the surface or in the atmosphere, but it is not certain that life has originated there. Nevertheless it is pertinent to consider an ordered sequence of biological exploration which will answer the question as to whether life has, does or could exist on Venus. Furthermore, until an adequate search for life has been completed, Venus should be designated as an biological preserve.

The suggested sequence of exploration is to first adequately define the Venusian environment to determine the

location of possible biotic zones. This phase should include a determination of the atmospheric temperature and pressure profile, the topographic features of the surface, the constitution of the atmosphere and surface material, the locations of liquid water, and the spatial distribution of solid or icy particulates in the atmosphere. Flyby and orbiting spacecraft can provide the initial gross measurements required.

This data should allow an identification of possible biotic zones on Venus. At this point two major alternatives are presented. Organic compounds such as hydrocarbons, amino acids and nucleic acids, which are common to all terrestrial life could be searched for using gas chromatography and mass spectrometry. This would be followed if necessary by direct detection of life. Alternatively direct life detection methods could be used to look for present living organisms, without the prior measurements of organic materials. Either alternative will require the use of atmospheric probes capable of controlled descent and perhaps landers.

The unmanned Mariner '67 Venus mission will make a contribution to the biological exploration of Venus. However, Voyager orbiter missions can make a more significant contribution in determining the location and extent of the biotic zones. For Voyager missions the requirements of the physical scientists, planetologists and biologists will be highly complementary. The subsequent search for organic compounds and life forms will share a technological and scientific commonality with the search for life on Mars.

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## 1. INTRODUCTION

It is now generally accepted that the origin of life was a natural, perhaps inevitable, step in the evolution of the Earth. Recent progress in cellular biology and biochemistry has provided a significant, but by no means complete, understanding of the evolutionary process from organic compounds preceding the first simple cells to the diverse and complex life forms presently abundant on the Earth. The suggestion of life on planets other than the Earth, has been applied, in the past, almost exclusively to Mars and has resulted in Mars being designated as a biological preserve. However, during the last few years there has been an increasing awareness that life or pre-life forms may exist elsewhere in the solar system and in the universe. A comprehensive report of a National Academy of Sciences study on exobiology in general and with respect to Mars in particular has just been published (NAS 1966). Perhaps the simplest definition of life is "something that is capable of information storage, replication, and the controlled transfer of energy".

Recognition of life forms, and whether they are living, is basically accomplished on Earth by human observation of growth and movement. This recognition is much more difficult without human observers but instrumentation for the direct detection of life forms is currently being developed. A simpler intermediate technique, which does not per se constitute recognition of life, is the unmanned detection of complex molecules such as amino acids, nucleic acids and nucleic acids which are common to all terrestrial life.

The purpose of the study reported here is to determine the mission requirements of the biologically-oriented measurements which may be important in the early exploration of Venus. There are clearly advanced planning implications if it is shown that indigenous life may have existed or could now exist on Venus. Important considerations would be commonality of detection systems for Mars and Venus, the requirements for sterilization of early entry probes or landers and the priority which should be given to an unambiguous determination of the biotic character of Venus.

The second section of this report discusses the characteristics of life as we know it on Earth. A third section reviews the present knowledge of the environment of Venus in terms of the possibility of life having arisen there. Also discussed is the ability of life to survive in the present environment. Finally a section is devoted to a discussion of the biological measurements which should be made in the early exploration of Venus.

## 2. TERRESTRIAL LIFE AND ITS ENVIRONMENT

The initial biological exploration of Mars and Venus will be based largely on the knowledge and experience gained with terrestrial life forms. It is therefore appropriate to briefly review this knowledge before considering Venus and its environment.

For life to persist on Earth there are certain identifiable fundamental requirements which are provided by the terrestrial environment, and these include water, a gaseous atmosphere, food sources and a restricted range of temperature and pressure. In addition it is possible to infer the probable conditions in which life was able to originate and to evolve to its present state on Earth.

### 2.1 Probable Evolution of Terrestrial Life

Table 1 shows a possible evolutionary sequence expressed in terms of chemical and biological constituents in the Earth's environment. The primary elements at the time of the formation of the solar system were probably hydrogen and helium in accordance with their cosmic abundances. The condensing hot Earth was unable to retain the hydrogen and helium but such compounds as water, nitrogen, ammonia and methane would be retained and

Table 1

## A POSSIBLE COURSE OF TERRESTRIAL CHEMICAL AND BIOLOGICAL EVOLUTION

| Suggested Evolutionary Order | Specific Items |
|---|---|
| Primary elements (cosmic abundance) | $H_2$, He, $O_2$, C |
| Simple precursor compounds (volcanism) | $H_2O$, $NH_3$, $CH_4$, HCN |
| Organic compounds | Hydrocarbons |
| Monomers | Amino acids, sugars, purines |
| Polymers | Proteins, enzymes, nucleic acids |
| Metabolizing coacervates | Protocell |
| Reproducing biopolymers | DNA |
| Reproducing cells | Photosynthetic microorganisms |
| Darwinian evolution | Aerobic organisms, plants, insects, animals |
| Humanoid | Man |

could well be abundant at the surface and in the atmosphere of the Earth as a result of early volcanic activity. In such an early non-oxidizing environment it has been clearly demonstrated by the now classic Urey-Miller laboratory experiment that ultraviolet light, electrical discharges, gamma radiation or even heat will synthesize organic molecules and biopolymers (Pattee 1965).

Fox (1965) has found an amino acid polymer or protenoid, in similar experiments under relatively dry conditions which may indicate that enzymes could have originated spontaneously. While the results of these experiments do not prove a similar chemical evolution on Earth they support the Oparin-Haldene theory of biomolecular origin which contends that the protocell evolved directly from systems of interacting organic molecules.

Recent experiments by Fox and Fukushima (1964) and Oparin (1965) illustrate the capacity of self-organization of macro-molecular complexes produced under simulated primeval conditions. Protenoids which have been produced by heating amino acids in lava, were found to form microspheres 2-7$\mu$ in diameter in aqueous solutions. They endured centrifugation, had a granular structure and were enclosed by double membranes. These are admittedly static structures but "metabolizing" coacervate* droplets have also been produced, which selectively absorb substances from their environment and release reaction products. Such coacervates may form the basis for a protocell.

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*Coacervate: An aggregate of colloidal droplets held together by electrostatic forces.

For example, a chlorophyll-containing coacervate droplet can catalyze a complex oxidation-reduction system. Ascorbic acid entering the droplet gives up hydrogen to chlorophyll in the presence of illumination. The chlorophyll transfers the hydrogen to a dye and becomes regenerated to its original state. Reaction products migrate into the external medium.

It is also likely that mechanisms for protein biosynthesis developed after the first proteins appeared abiogenetically. The culmination of the evolutionary transition was the appearance of DNA which through its control of genetic codes and templates for protein biosynthesis enabled the subsequent evolution of biological species.

Although in the evolution of living cells single cells were presumably formed in an oxygen-free environment, forms of life consisting of more than one cell need oxygen in order to obtain enough energy to survive. Berkner and Marshall (1965), have suggested a mechanism for this transition on the Earth, whereby photodissociation of water provides an increasing oxygen abundance and, in addition, an ozone layer in the atmosphere for protection against lethal ultraviolet rays. As oxygen concentrations reached levels permitting respiration, new evolutionary opportunities were created for the development of complex multicell organisms with advanced mechanisms of energy capture, control, and utilization.

An alternative biological origin has very recently been suggested by Abelson (1966). He questions the methane-ammonia hypothesis for the early terrestrial atmosphere and indicates that HCN (hydrogen cyanide) could be a principal product of interactions between outgassed volatiles. Ultraviolet irradiation of HCN solutions at pH 8-9 would yield amino acids and other important substances of biologic interest.

## 2.2 Temperature and Pressure Limitations

Terrestrial life has been found in habitats with wide extremes of temperature. The lowest temperature capable of supporting active life appears to be somewhat below 0°C provided the aqueous medium remains liquid. Samples of water from Don Juan Pond (Antarctic) maintained at their original temperature of -23°C for several days were found to contain organisms that were able to grow and reproduce in the high saline concentration present in the pond (Meyer 1962). There is probably no limit to the lower temperatures at which certain microorganisms can be maintained in the dormant state. However, they must be brought to an active state without undergoing adverse phase transitions during thawing or reconstitution.

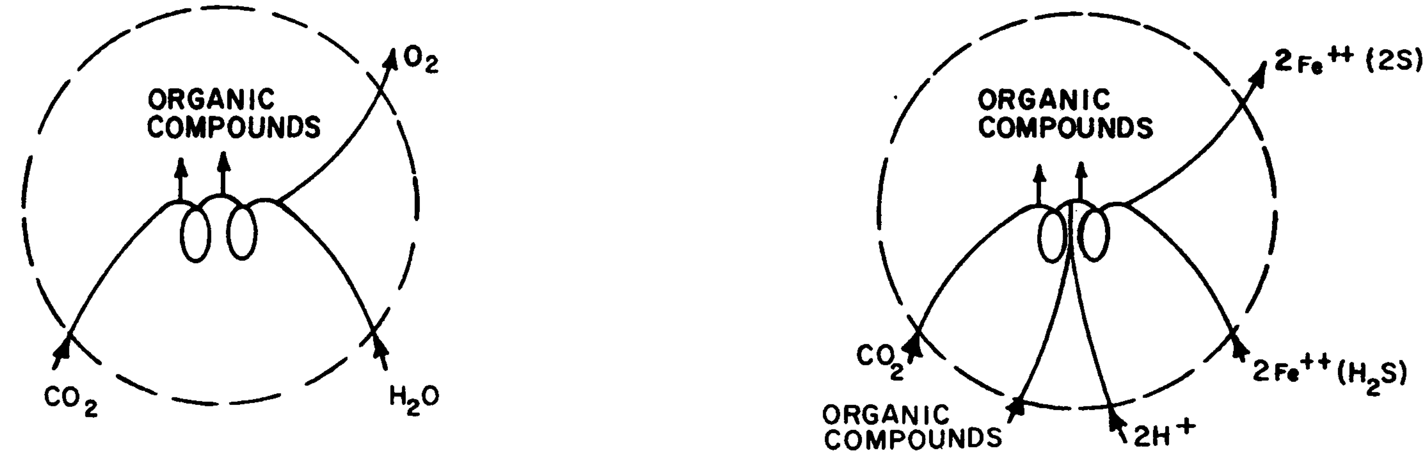
Algae and thermophilic bacteria are known which can grow at temperatures as high as 89°C. However, Kempner (1963) reported that organisms metabolize with incorporation of radioactive phorphorus only at temperatures below 73°C. Thermal studies in vitro conducted by Arca et al. (1963) showed that soluble RNA will not accept amino acids for protein biosynthesis at temperatures above 75°C. It is quite likely that the critical temperature for the survival of microorganisms is that which causes protein or nucleic acid denaturation.

The pressures that support terrestrial life range from the thin atmospheres atop the Himalayan and Andes mountains to the depths of the oceans. Peruvian Indians are known to inhabit a zone at 16,000-18,000 ft elevation with an atmospheric density about half that at sea level. Biotic zones with lower life forms are found in the Himalayas up to an elevation of 20,000 ft. Ocean depths which are known to support life despite high pressure and lack of sunlight exceed 30,000 ft and 900 atm pressure.

### 2.3 Food Sources

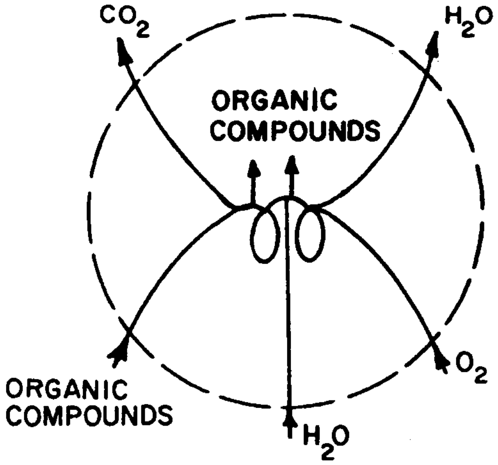
Life on Earth presently consists of a balance between aerobic photosynthetic organisms, such as plants, and oxygen and food-consuming animals. Schematic diagrams of the most common metabolisms are shown in Figure 1. The very few carbon dioxide fixing bacteria that utilize iron or sulphur oxidation as an energy source are considered special terrestrial forms although they abound in marine muds. There is no apparent reason why these forms could not predominate in another environment.

The basic food requirement of living cells is carbon. The simplest carbon source is carbon dioxide which is required by all bacteria. In cells capable of photosynthesis, carbon dioxide is transformed into organic carbon compounds via solar energy, using chlorophyll as a catalyst. Anaerobic bacteria achieve this conversion without utilizing free oxygen but do require organic growth factors. They are observed today, for



**AEROBIC PHOTOSYNTHETIC (REVERSIBLE)**
(SOLAR RADIATION ENERGY SOURCE)

**ANAEROBIC IRON (SULPHUR) METABOLIZING**
(INORGANIC ENERGY SOURCE)



**AEROBIC SUBSTRATE METABOLIZING**
(ORGANIC ENERGY SOURCE)

FIGURE I. SCHEMATIC REPRESENTATION OF TERRESTRIAL BIOTA example, as purple bacteria. Aerobic photosynthesis is far more general with water and carbon dioxide as the primary intake and oxygen as the byproduct.

The food-consuming aerobic cell produces water by cyclically transferring hydrogen to oxygen. Carbon dioxide is evolved and complex organic materials are synthesized in the metabolic process.

## 2.4 Gaseous Atmosphere

Oxygen is a necessity for most food-consuming organisms and is now freely available in the Earth's atmosphere. The present balance is such that plant life is able to provide sufficient oxygen to sustain oxygen-consuming life forms. However it should be noted that a 100 percent oxygen atmosphere on the Earth would kill almost all life within a few weeks unless an adequate adaptation mechanism could evolve. Alternatively a few anaerobic life forms do exist which can survive in the complete absence of oxygen. Free molecular oxygen cannot therefore be considered as absolutely essential to life despite the fact that the oxygen atom provides an extremely efficient energy transfer through oxidation.

Ozone (or some molecular species with similar ultraviolet absorbing characteristics) is, however, essential to the preservation of life. The ozone layer in the upper atmosphere absorbs strongly in the wavelength range between 2000 and 3000 Angstroms and affords an essential protection to multicell organisms. Present day nucleic acids are most sensitive to radiation at 2630 Å and proteins at 2750 Å.

Carbon dioxide plays an essential role in photosynthetic and other biochemical fixation mechanisms. Although present in the terrestrial atmosphere only as a trace constituent, it is the sole carbon source for plants and many microorganisms and is a supplementary carbon source for higher animals.

In view of the presence of nitrogen and other more inert gases in the atmospheres of the terrestrial planets, the role of these gases in the evolution of the biospheres may be of some importance, for instance, as a dilutent. However no adverse effects on the growth and replication of microorganisms is generally attributed to these gases. In fact nitrogen is utilized directly by nitrogen-fixing bacteria, which are symbiotic with other microbial or plant systems. It should be recognized however, that supposedly inert gases may exert unique metabolic effects when present in extreme environments. For example it is known that at 12 atmospheres of pressure, nitrogen has narcotic effects on man and animals.

## 2.5 Water

Water is essential for terrestrial life. It is the medium for nutrient transport, it actively participates in virtually all biochemical reactions, and plays a dominant role in molecular and tissue morphology. While other liquids such as ethanol, glycerol, glycols, and silicones may be tolerated to some degree, there is clearly a limit to water displacement in each case. A dynamic equilibrium between water and macro-molecules (proteins, carbohydrates, lipids), operates by means of hydrogen bonding. This equilibrium controls the association of most molecules in aqueous media to the degree that without water, life as constituted on Earth would be impossible.

The oceans or other bodies of water on Earth are believed to have first supported terrestrial life. Indeed, at the present time a high diversity of plant, animal, and microbial life is found in the seas at varying depths, temperatures, and salt concentrations. Microorganisms that thrive in hydrocarbons, strong salt solutions, and even sulfuric acid are believed to exist in aqueous droplets or on interfaces in these media. Although Abelson (1960) contends that bacterial growth and reproduction require a relative humidity of 30 percent, it should be noted that microorganisms depend specifically upon their micro-environments for their metabolism and not on the general humidity of their surroundings. Of direct importance is the water activity (water capable of exerting vapor pressure) in the immediate vicinity of the cell. If this minute supply of water is replenished from an adjacent source as it is utilized by the organism, the stage is set for cell metabolism and multiplication in a medium that can be relatively dry. Plants also show this ability to thrive under apparently extreme conditions. For example, cactus plants entrap water against an arid environment and halophytic plants take up water from concentrated salt solutions against high osmotic gradients.

It is apparent from this brief survey of the environment supporting terrestrial life that the normal environment for man encompasses only a small range of the total span of parameters for other terrestrial species. Thus, while water is a universal requirement for life, apparently minute concentrations may be adequate, while fairly wide ranges in pressure, temperature, oxygen, carbon dioxide and energy sources are tolerated. The wide ranges of conditions tolerated by living organisms in the biotic zones of the Earth are of particular interest when the possibility of life on Venus is considered.

## 3. THE POSSIBILITY OF LIFE ON VENUS

There are two major considerations in determining the possible existence of life on Venus. The first concerns the ability of the present Venusian environment to support life, and the second the plausibility of life, of a terrestrial or non-terrestrial type, originating, becoming established and evolving.

### 3.1 The Venusian Environment

The current knowledge of Venus has been reviewed in detail in a recent IITRI report (Dickerman 1966). The most important biologically related parameters are temperature, pressure, water, carbon dioxide and oxygen content, wind effects and surface topography.

The temperature at, or slightly below, the cloud level is estimated to be between 250°K and 450°K (Spinrad 1962) and at the surface to be well over 500°K. Therefore there will probably be a temperate zone at some level in the atmosphere below the clouds, although its position and extent cannot be predicted from present data.

Spectroscopic pressure determinations have indicated pressures within or below the clouds of between 2 and 5 atmospheres corresponding to the temperature range of 250-450°K. Spinrad (1962) has estimated that the pressure at the bottom of the $CO_2$ absorbing layer is near 10 atmospheres and this is taken as a lower limit for the surface pressure on Venus.

Recent work by Dollfus (1963) and by Bottema, Plummer and Strong (1964) has indicated the presence of about 100μ of precipitable water vapor. This abundance refers to the atmosphere at some level well above the surface of Venus.

It is worth pointing out that water can exist in the liquid phase at temperatures higher than 373°K if the pressure is high enough. A curve showing the liquid phase of water as a function of pressure is shown in Figure 2 with an indication of the possible range of conditions on the surface and in the atmosphere of Venus.

The pressure effect on the freezing point of water is very small. The depression is only 2.5°C at a pressure of 350 atmospheres.

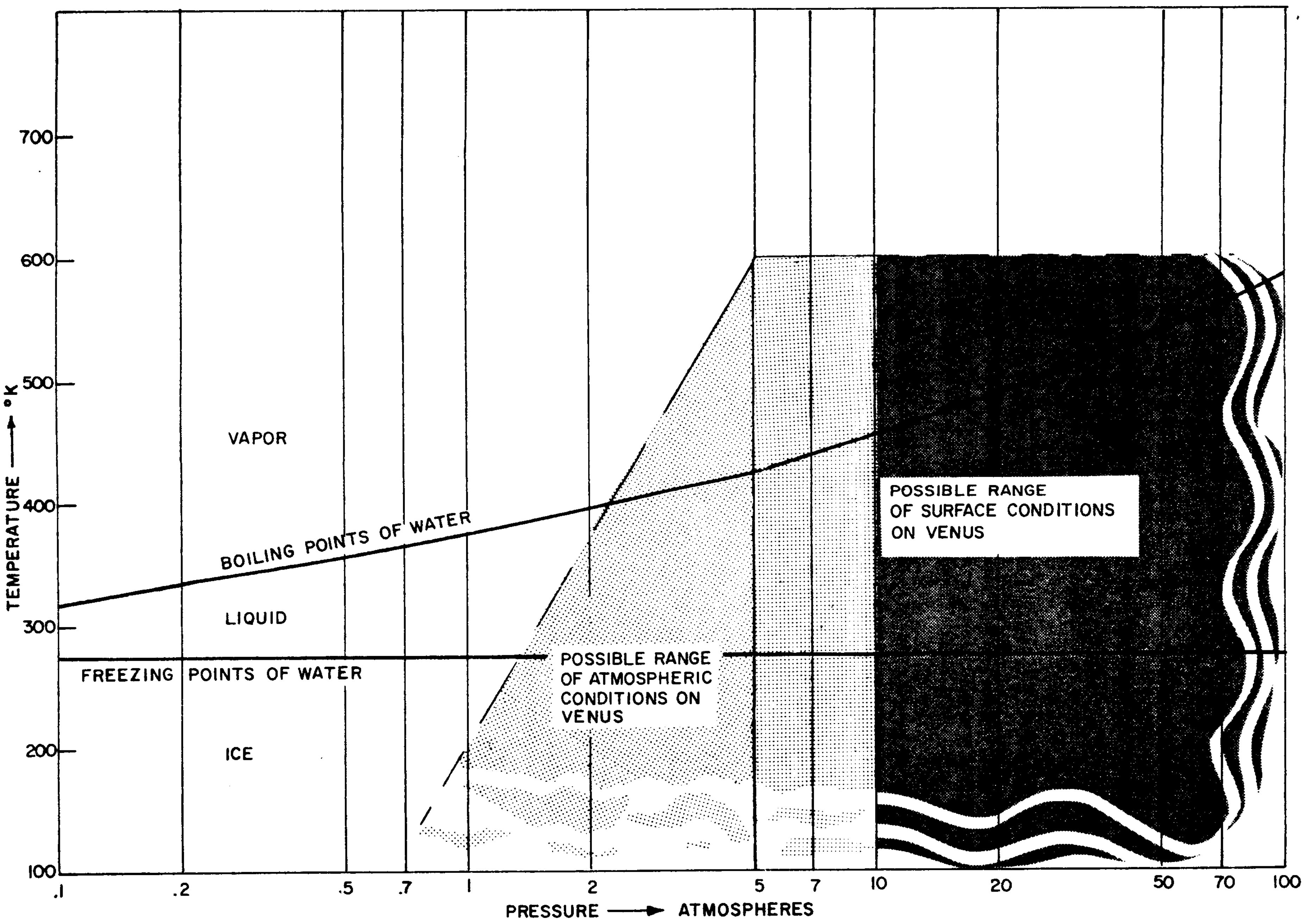


FIGURE 2. LIQUID PHASE OF WATER AS A FUNCTION OF PRESSURE

The most certain feature of the Venusian atmosphere above the cloud layer is the presence of large quantities of carbon dioxide. At present the abundance is accepted as being between 100 and 1000 meter atmospheres with the lower values being preferred.

Considering this rather large amount of $CO_2$ it is reasonable to expect at least some oxygen in the atmosphere. Spinrad and Richardson (1965) have recently detected no free oxygen with an estimated upper limit of about 57 centimeter atmospheres. The presence of ozone has been deduced by Evans (1966) from a rocket-borne UV experiment and the amount was estimated as 0.1 to 0.03 centimeter atmospheres. This is consistent with the above upper limit for oxygen.

The major constituent in the atmosphere of Venus has not been identified but it is believed that nitrogen is the most probable. Upper limits on other gases have been set by Kuiper (1952) as 100 cm atm of $N_2O$, 20 cm atm of $CH_4$, 3 cm atm of $C_2H_4$, 1 cm atm of $C_2H_6$ and 4 cm atm of $NH_3$.

Many models have been proposed for the Venusian atmosphere below the clouds. The most plausible model is due to Sagan (1960) which relies on water vapor in addition to $CO_2$ to provide infrared opacity and the maintenance of the high surface temperature through the greenhouse effect. With water present, ice crystals should form in the clouds. However in nearly all of the proposed models, the fairly steep temperature gradient in the lower atmosphere would cause circulating winds which may entrain dust from the surface of Venus.

The analysis of the radar reflectivity of Venus has indicated a dielectric constant between 3 and 7 (Muhleman 1963). This is too small to permit extensive smooth oceans of water and too large to permit smooth oceans of hydrocarbons. The roughness of Venus appears to be similar to that of the moon (Victor and Stevens 1961) and the dielectric constant is consistent with dry terrestrial type soils. Tentative identification has been made of a locally elevated surface or mountain range on Venus.

The past environment of Venus is very difficult to deduce with any degree of certainty. There is little knowledge of even the present conditions on the surface or in the lower atmosphere. However the density, mass and gravity of Venus and the Earth are similar, they both occupy approximately the same region of the solar system and it may be assumed that they both had a similar origin and similar initial atmospheres. If this is true the atmosphere of Venus must have evolved differently from the Earth's to account for its much greater density and different composition. The differences may be due to a history of higher temperatures on Venus since the level of incident solar radiation is approximately twice that on the Earth.

### 3.2. Life on Venus?

Table 2 lists the environmental parameters, on Venus, of biological interest and compares them with the conditions under

Table 2

## SUITABILITY OF VENUSIAN ATMOSPHERE FOR SUPPORTING LIFE

| Environmental Parameter | Extremes for Terrestrial Life | Venusian Environment | Remarks |
|---|---|---|---|
| Temperature-Max.<br>Min. | +89°C<br>-23°C | +350°C (surface max.)<br>-25°C (top of clouds) | Temperate zones may exist, probably in atmosphere. |
| Pressure -Max.<br>Min. | 900 atm<br>1/2 atm | 5 atm (surface)<br>1 atm (top of clouds) | Pressure should not inhibit life |
| Oxygen | 1.7 km atm (atmospheric abundance) | $5.7 \times 10^{-4}$ km atm | May be adequate for aerobic as well as anaerobic forms. |
| Carbon dioxide | $2 \times 10^{-3}$ km atm (atmospheric abundance) | 1/2-1 km atm | Favors $CO_2$ fixing forms. |
| Nitrogen | 6.2 km atm (atmospheric abundance) | ? (possibly 10 km atm) | Not toxic |
| Water | $2 \times 10^{-2}$ km atm (atmospheric abundance) | $10^{-4}$ km atm | May be adequate for life in localized zones. |
| UV absorption | Ozone | Ozone (+?) | Probably adequate protection from ultraviolet. |
| Food sources | $CO_2$, organic material | $CO_2$ | Adequate carbon source |

which life exists on the Earth. There is nothing that has been discovered so far in the atmosphere and environment of Venus that precludes the survival of indigenous life on the planet. It is probable that some water is available in the liquid state, if not on the equatorial surface, then at higher latitudes, at high altitudes or in the atmosphere. This indicates that life on Venus may be confined to biotic zones, probably in the atmosphere but possibly on the surface. Given water, then, the pressure-temperature combination in the region of this water should not inhibit life. The constituents of the atmosphere, in particular carbon dioxide and oxygen, are conducive to life and no obviously toxic constituents have been detected. Life forms which would be well adapted to living on Venus may well be unfamiliar to us but could include advanced anaerobes utilizing photosynthesis and advanced thermophilic forms capable of existing at high temperatures.

The suggestion of strong winds may have some influence on the biotic potential of the lower atmosphere. If the temperate zones are limited to the atmosphere, then the possible presence of dust or even ice particles entrained in the atmosphere may provide a base upon which living organisms can settle and multiply. The effects of strong winds themselves are difficult to assess. Although man and many plants cannot survive without protection in severe atmospheric turbulence, there appears to be no reason why self-replicating organisms could not.

The vast diversity of life on the Earth and the environmental conditions supporting it coupled with the admittedly limited knowledge of Venus lead to the conclusion that, if life could originate on Venus, then it could survive. The large remaining problem therefore is whether life has or could originate on Venus. The answer to this problem will only be provided in the final analysis by finding or not finding life after an adequate search. At present all that can be said is that if Venus did indeed have a propensity of either methane-ammonia or HCN in its atmosphere then presumably prebiotic organic compounds could have been formed. Whether this environment has or could exist for a sufficient time for life to become established is indeterminate. If however life did become established, terrestrial experience would indicate that it could evolve, adapt and survive.

## 4. THE SEARCH FOR LIFE ON VENUS

The conclusion reached from the previous sections is that there is a very real possibility that life may have, does, or could exist on Venus. It is felt that a better determination of this possibility and perhaps the eventual detection of life can be obtained in an orderly manner which is complementary to the planned exploration of Venus.

The search for life on Venus should be aimed at direct life detection. However to avoid an unnecessary proliferation of sophisticated Automated Biological Laboratory missions it is suggested first that the biotic zones, where life is possible, be clearly identified in location and extent. This can be done from orbiting and flyby missions. Once these zones have been clearly identified, then a decision must be made to either search for organic materials as an indicator of which zones are most likely to be supporting life or to invoke direct life detection without this intermediate step. In the event that no life is found after an adequate search, then at a later time a search for fossils of an earlier life should be considered.

In solar system terms the exploration of Venus has a high priority which is only superseded by the exploration of Mars and the moon (Space Science Board 1965). Accordingly over the next 10 to 15 years it is probable that flyby and orbiting missions to Venus will be accomplished and that atmospheric probes will penetrate and sample its dense atmosphere and perhaps the first survivable landing missions will be instituted.

The initial data from Venus which are required for biological interpretation are similar to the initial data required for physical and planetological reasons. In the latter case the primary purpose of the initial data is to better define the constitution, temperature and pressure profiles of the Venusian atmosphere and to resolve a current point of scientific dispute regarding the surface temperature on Venus.

The only mission approved by NASA at the present time is the 1967 Mariner Venus flyby mission which is expected to contain radio occultation experiments at two frequencies to investigate the pressure and constitution profiles of the atmosphere, an ultraviolet photometer to investigate the constituents of the upper atmosphere, and a plasma probe, magnetometer and trapped radiation detector for monitoring the environment of Venus. For biological interpretation more emphasis on temperature measurements and water detection would be desirable. The accuracy required for the initial detection of temperature and water is compatible with flyby missions and data received from an early flyby could assist in the design of detectors for later more sophisticated missions.

The advent of Voyager type orbiter missions to Venus will provide a good opportunity to give the biologically oriented experiments an adequate emphasis. Infrared and microwave radiometry can provide adequate thermal mapping of the surface and atmosphere to localize the temperate zones. Infrared and ultraviolet spectrometry could provide a good estimation of the location and quantities of free water in the atmosphere and permit the measurement of ozone. Radar could provide a gross topographic map of the surface and with microwave radiometry could provide an indication of the distribution of surface materials. Occultation between stars and the spacecraft and radio occultation between the spacecraft and Earth can be used to refine the estimates of the mean molecular weight of the atmosphere and the pressure profile. These orbiter measurements are of interest here in defining where, if at all, the potential biotic zones on Venus exist and to provide an estimate of their extent, continuity and stability. However these measurements should not conflict with the requirements of the physical science investigations and if anything will impose fewer constraints on the missions because of the gross nature of the information required. Furthermore such experiments are entirely compatible with the anticipated technological developments which will form part of the earlier investigations of the moon and Mars.

This first phase of biological exploration of Venus is suggested as a logical complement to the physical and planetological exploration. It does not involve the search for life but rather a better understanding of the biotic potential of the environment at least in terms of the knowledge of terrestrial life. Having achieved this objective, a major decision must be made in defining the subsequent search for life.

Firstly the investigation of determined temperate zones can take the form of a detailed search for organic compounds which are indicators of the possibility of the evolution of life but do not constitute a detection of life. This course would be most cost effective if, at that time, there is considerable doubt as to the possibility of life on Venus, if direct life detection experiments are found to be inadequate or ambiguous, or if an early definition of the biological status of Venus is required. Organic compounds such as hydrocarbons, organic acids and aldehydes are of particular interest and can be measured with sample collection by an atmospheric probe and a combination of gas chromatography and mass spectrometry. The constraints that this type of measurement will place on the probes are that the entry point of the probe will be related directly to the location of the potential biotic zones and the rate of descent through the zones of interest must be controlled to allow for the relatively time-consuming sample collection and analysis. In the case of survivable landers the only major constraint will be the selection of the landing area.

Secondly the temperate zones can be investigated with direct life detection systems. These devices are expensive and operationally demanding, but if an adequate development and experience will have been obtained from the Automated Biological Laboratory for Mars, then it is feasible to consider them for biological exploration on the surface and in the atmosphere of Venus without a previous determination of the distribution of organic materials. Otherwise they would be used if required after the search for organic compounds.

The biological exploration of Venus has some implications in terms of the advanced planning of Venus missions.

Firstly there seems to be little difference between the measurements that will be required to satisfy the initial physical, planetological and biological objectives of exploration using either flyby or orbiting spacecraft. However, at this time it appears that there exists a real possibility for the existence of indigenous life on Venus and until it can be clearly shown otherwise, Venus should be treated as an biological preserve. Furthermore the specific requirements which will probably be associated with biologically oriented probes may mean that they will not be used until after the more general atmospheric probes or even landers. Thus the questions of sterilization of the early probes and landers must be considered until the full biological sequence of exploration has been determined. In effect the danger of biological contamination of Venus must be treated now in a similar fashion as for Mars. Finally in terms of the required experimental technology it appears that the biological exploration of Venus can be coupled to that of Mars. The measurement techniques will have a high degree of commonality.

It is clear that even a minimal biological exploration of Venus will require atmospheric probes and survivable landers, which may be used in conjunction with either flyby or preferably orbiting spacecraft. Environmental data will be obtained by the physical scientists, but the measurements to be made by the probes will be quite specifically biological in design and operation. However there is a significant possibility that biologists will not make demands for experiments on Venus missions until after the environmental data has been obtained. In fact NASA should be prepared well in advance of these demands so that they can be accommodated into a logical and timely series of missions.

## 5. CONCLUSIONS

The mission requirements of biological measurements on Venus cannot be completely specified at this time. However the following conclusions can be drawn.

- Life could survive on Venus probably in localized biotic zones.
- Whether life has originated is indeterminate.
- Venus should be treated as a biological preserve until it is shown that life does not exist there.
- The planned Mariner '67 Venus mission will make a contribution to the biological exploration of Venus.
- Voyager-type missions should make a large contribution to the identification of biotic zones in common with the physical science and planetological objectives.
- Entry probes will be required for the detection of organic compounds and life forms.
- Atmospheric probes should have the ability to remain at given altitudes for considerable periods (days).
- Landers, if required for biological measurements, are likely to be needed at high latitudes.
- NASA should be prepared for an extensive biological exploration of Venus even in advance of the identification of biotic zones.

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