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April 15, 1971

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IRIS BIOLOGICAL EXPERIMENTS

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ABSTRACT

The types of data to be obtained from the Mariner Mars '71 Infrared Interferometer Spectrometer (IRIS) experiment have been examined for the inferential information they may yield regarding the possibility of Martian surface biota. The IRIS will analyze the types and concentrations of trace gas constituents in the Martian atmosphere and, in wavelength regions where no gases absorb, the IRIS will also obtain reflectance data from the surface of Mars.

Regarding surface reflectance, our results indicate that neither biological nor organic material exhibit characteristic reflectance signatures in the range of the IRIS other than a black body response. These findings make it unlikely that definitive biological inferences can be drawn from the IRIS reflectance data. However, biological materials will quench the SiO_2 reststrahlen which will readily appear in one IRIS window. Thus, the possibility of inferring biological or organic material by quench of SiO_2 reststrahlen, while remote, does exist. The success of this approach will depend upon a relatively uniform distribution of SiO_2 on the Martian surface and upon the reliable elimination of other possible quench agents. One important piece of surface information that will be obtained from the IRIS relevant to biology will be the determination of whether or not liquid water can exist on the surface of Mars.

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Inferential information related to life on Mars may be obtained from analysis of atmospheric constitutents. The IRIS is capable of detecting small amounts of trace gases in the Martian atmosphere which would reflect both biological and non-biological processes on the planet. A study of terrestrial metabolism has indicated the most important biological gases to be O_2, H_2O, CO_2, H_2, CO, CH_4, H_2S, S_2O, N_2, NO, N_2O, and NH_3. Most of these gases are found to varying degrees in the Earth's atmosphere. Other gases of interest include O_3, NO_2, N_2O_3, SO_2, and SO_3. While these do not play a significant role in terrestrial metabolism, they could conceivably play a role in extraterrestrial life processes. Of these gases, the IRIS can detect all except the diatomic gases lacking a dipole moment (O_2, H_2, and N_2) and CO and NO which lack fundamental absorption bands in the range of the IRIS. Also appearing in the Earth's atmosphere as a result of terrestrial metabolism are a variety of organic compounds, including hydrocarbons, terpenes, and their oxygenated derivatives. Terpenes occur widely as natural products and are oxidized in the Earth's atmosphere thereby producing a characteristic "blue haze" often seen in the country and over areas of heavy foliage. Absorption spectra of typical terpenes are also within the range of the IRIS.

On the basis of these studies, we have recommended that signatures and detection limits of many of these gases and hydrocarbons be

established prior to analysis of the IRIS data. First priority for signature analysis has been assigned to O_3, H_2O, CO_2, CH_4, H_2S, N_2O, and NH_3. Second priority organic compounds include the terpenes isoprene, α-pinene, myrcene, citral, geraniol, limonene, camphor, and farnesol. Finally, signatures should also be established for NO_2, N_2O_3, SO_2, SO_3, and S_2O. In addition, since recent studies with a simulated Martian atmosphere have indicated that formaldehyde and acetaldehyde may be present on Mars, these compounds are also recommended for signature study. Detection of any of these compounds, particularly in disequilibria, may be indicative of metabolic processes on Mars.

While detection of a trace gas may be biologically significant, it may also be possible to obtain more definitive indications of surface metabolic activity from the IRIS data. Thus, variations in gas concentrations or in isotopic ratios with time and location could reflect life processes. Metabolic activity could also be implied from vertical concentration gradients of gases or from certain anomalies in the concentration of a particular gas. Of these approaches, detection of anomalies, based on a thorough knowledge of atmospheric photochemistry, offers the highest promise.

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I. INTRODUCTION

The purpose of this program is to design and conduct an experiment to obtain inferential information concerning the possibility of life on Mars from the Mariner Mars '71 Infrared Interferometer Spectrometer (IRIS) data. Two approaches to the problem are being followed. First, reflectance spectra will be examined for the possibility of making biological inferences from the Martian surface. Second, a study is under way to explore possible results of biological significance that may be obtained from data on atmospheric analysis of gaseous constituents in the Martian atmosphere. This report summarizes our findings to date.

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II. BIOLOGICAL STUDIES

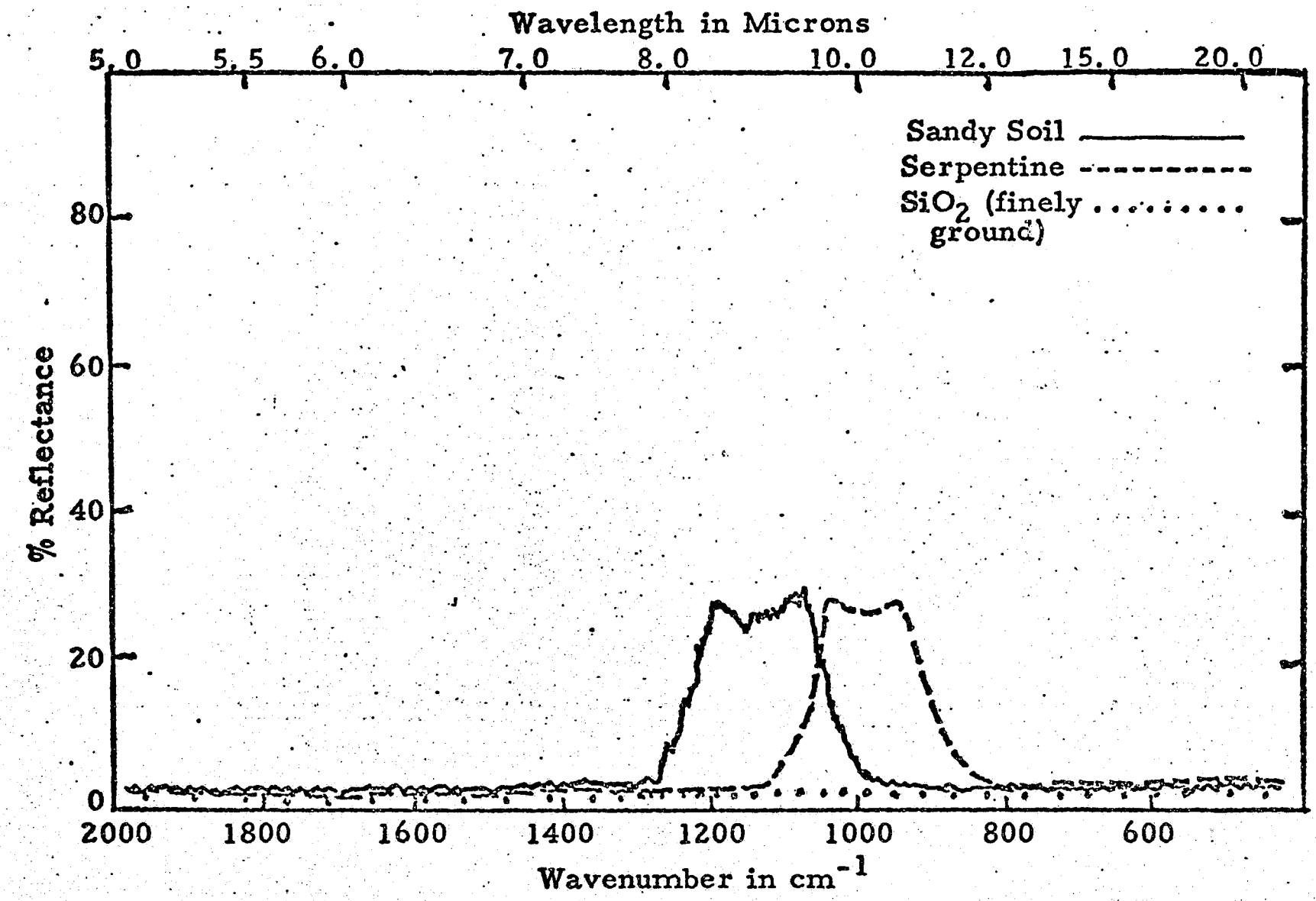
A. Inferences to be Made from Surface Phenomenon

1. Reflectance of Inorganic, Organic, and Biological Samples

To obtain biological inferences from surface phenomenon, it is first necessary to examine inorganic, organic, and biological samples for characteristic reflectance spectral signatures. To this end, sample holders and a rotating reflectance unit were fabricated at Goddard for the Cary 90. The reflectance unit and sample holder were designed to minimize reflectance by the sample holder itself and heating of the sample during spectral analysis. Several samples were then selected to illustrate the reststrahlen effect exhibited by certain inorganics, reflectance of organic and biological samples, and effects of mixing inorganic samples with organic or biological material.

a. Inorganic Reststrahlen Effect

For this part of the investigation, finely ground SiO_2, sandy soil, and serpentine rock were used to obtain spectra. Both sandy soil and serpentine rock contained SiO_2 although the content in serpentine is considerably less. The spectra obtained from these samples are schematically illustrated in Figure 1. The spectrum of sandy soil contains the characteristic double peak reflectance from approximately 1300 - 1000 wavenumbers (8 - 8.5 μ). A similar spectrum is obtained for serpentine, although the position of the double peak is shifted toward longer wavelengths,



Reflectance Spectra of Sandy Soil, Serpentine, and Finely Ground SiO_2 (Cary 90 Recording Spectro-

Fig. 1

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1100 to 800 wavenumbers (10 - 10.7μ). On the otherhand, no reflectance is obtained with finely ground (100 mesh) SiO_2. The following principles are illustrated by these data:

- SiO_2 has a characteristic double peak reststrahlen from 1300 to 1000 wavenumbers.
- The position of this reststrahlen effect depends upon the concentration of SiO_2 in the sample. As the concentration decreases, the reflectance is shifted toward longer wavelengths.
- As the size of the reflecting particle decreases, the extent of the reflectance also diminishes. Thus, finely ground SiO_2 has no reflectance whatever.
- A rotating sample shows more "noise" than a stationary one because of the lack of a homogeneous reflecting surface (data not shown).

According to Dr. Warren Hovis at the Godaard Space Flight Center, other inorganics showing reststrahlen (provided they are of sufficient particle size) are diamond, saphire (15μ), SiO_2 containing quartz (two bands at 8.8 and 18-25μ), and gypsum (i.e., $CaSO_4$ or $CaCO_3$, 9μ). Of these, SiO_2 is the only inorganic that shows the shift in wavelength reflectance with concentration.

The data obtained from the Cary 90 represent reflectance spectra while those obtained from the IRIS will represent emission spectra. These spectra are related by Kirchoff's Law; i.e.,

E = 1 -R (emission equals one minus reflectance). Emission surface spectra appear as black body curves which are interrupted only by atmospheric gases which absorb in the wavelength region of the IRIS (5 - 50μ). "Windows" to the surface occur in areas where there is no gaseous absorption. In these "windows", any material reflecting from the surface will cause small deviations from the perfect emissivity (E = 1) spectra at the wavelength of the characteristic reststrahlen. The inorganics discussed in this section would thus be detectable provided they are present in sufficient quantity (the amount of reflectance depends on the percent of reflecting area) and are sufficiently large in particle size.

b. Reflectance of Organic and Biological Samples

Glucose, glycine, pepsin, lyophilized whole cells of *Micrococcus luteus*, lettuce leaves, and walnut leaves have been examined to determine whether organic and biological material have a characteristic reflectance. It should be noted that, while the first four of these samples are small in particle size, the leaf samples are large. During the course of these scans, the rotating reflectance unit adapted for use in the Cary 90, combined with a low source and a rapid scan speed, was successful in maintaining a relatively low temperature (approximately 35 - 40°C). The results show that each sample failed to exhibit any reflectance throughout the wavelength range of the IRIS.

In each case, the spectrum obtained was essentially identical to that obtained for finely ground SiO_2 (Figure 1). According to Dr. Hovis, biological reflectance has never been observed in these wavelengths, although other investigators have also looked for it.

c. Effect of Combining Inorganic with Organic or Biological Material

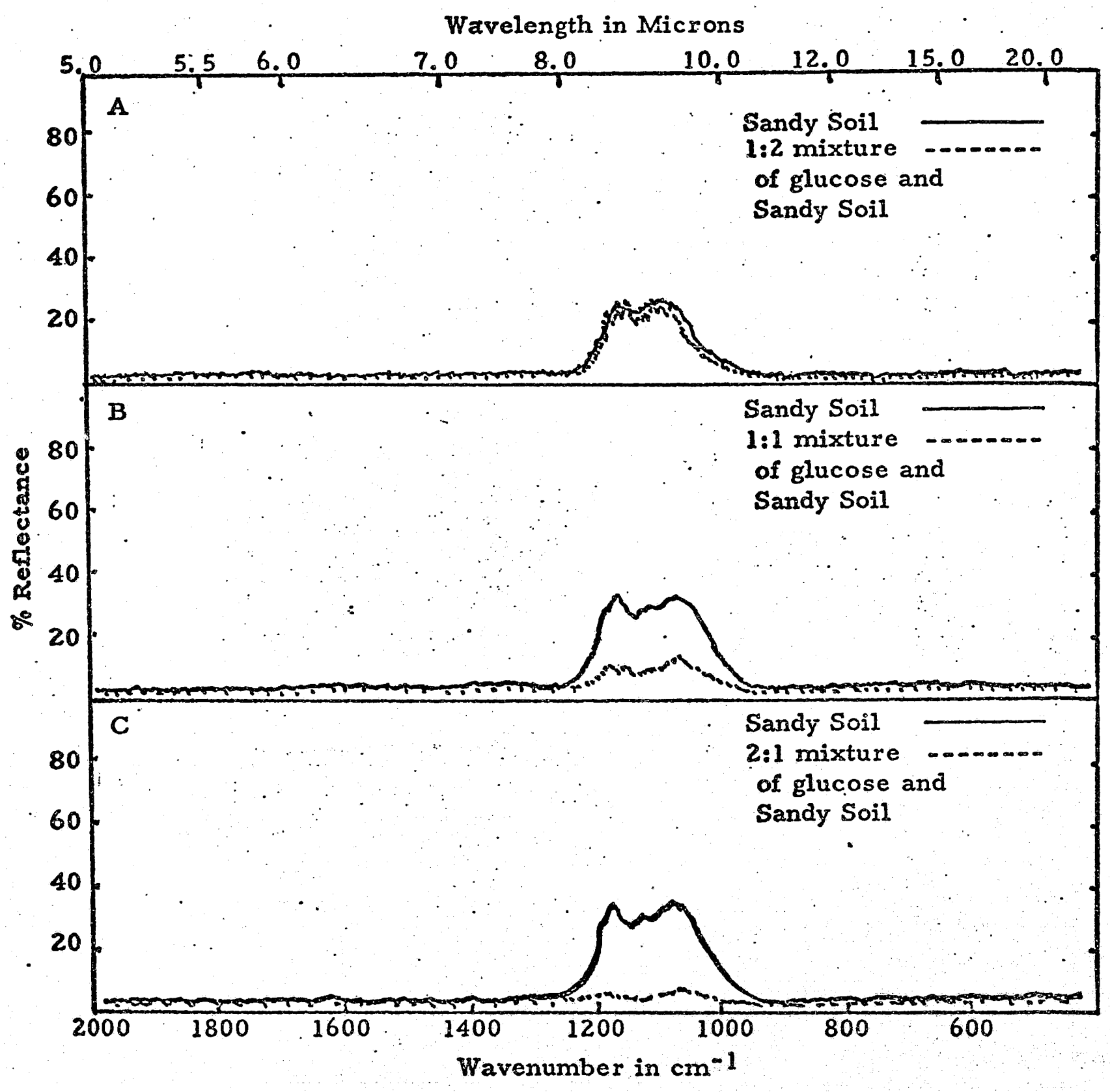
The following three experiments were conducted to study the effect of organic material on the reststrahlen of sandy soil:

- Sterile, autoclaved, sandy soil was compared to sandy soil known to contain microorganisms. No significant difference in reststrahlen was observed between the two samples.

- Since sandy soil produces a reststrahlen effect while glucose exhibits no reflectance, mixtures of glucose and sandy soil were prepared and examined. Figure 2 schematically presents the results of this experiment. As shown, the presence of glucose decreases the extent of sandy soil reststrahlen.

- Sandy soil was completely covered with walnut leaves. These leaves resulted in a complete quench of the SiO_2 reflectance. When the leaves only partially covered the soil sample, the spectrum shown in Figure 3 was obtained. This spectrum detects the rotation of the sample; as the sample rotates, first sand and then a leaf comes into the reflecting beam. Thus, the spectra "jumps" from that characteristic of sand to that characteristic of a leaf.

It may be concluded from this series of experiments that organic or biological material will quench reststrahlen roughly in proportion to the field of view covered by the organic material.



Quench Effect of Glucose on Reflectance of Sandy Soil

Fig. 2

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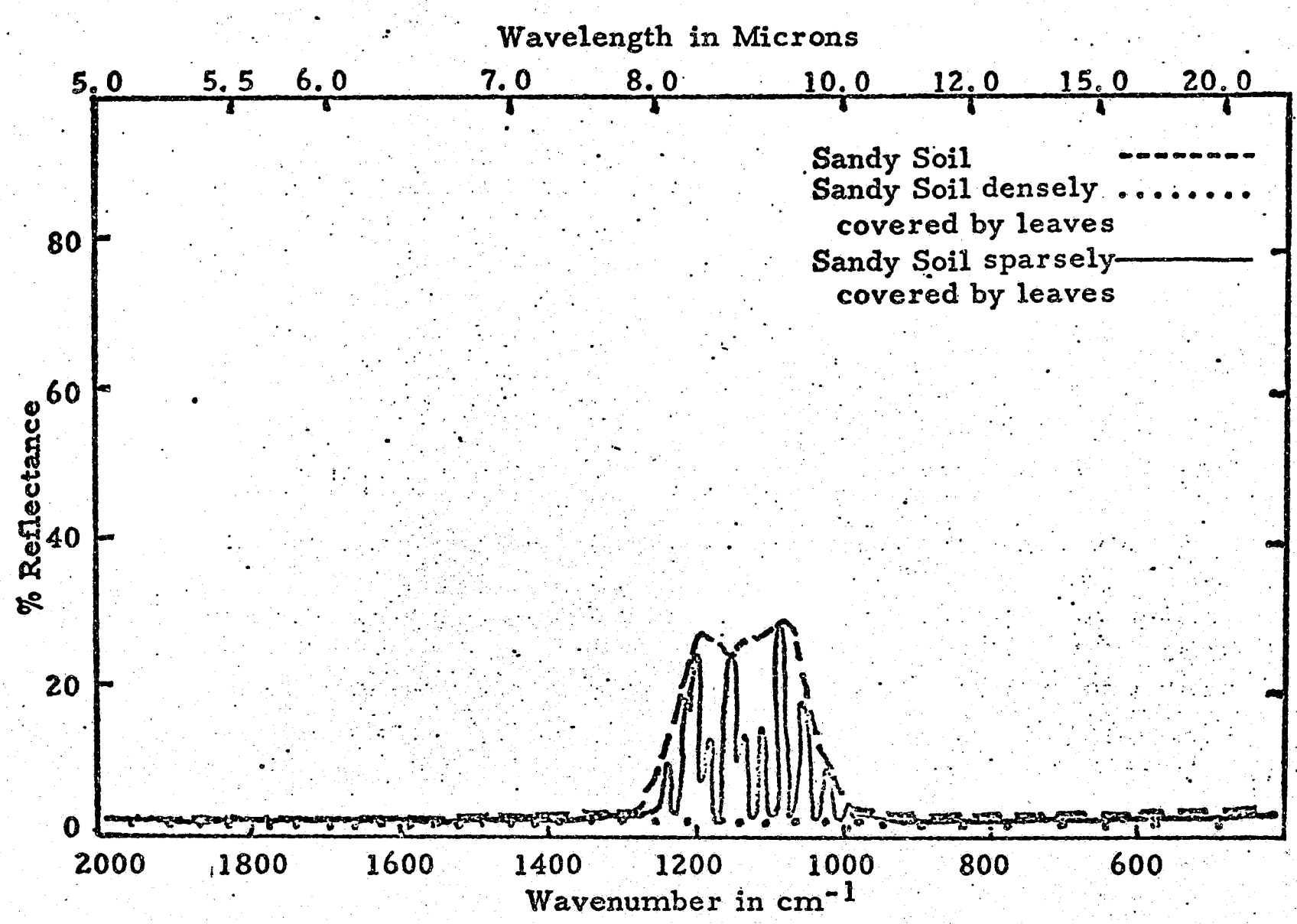

Quench Effect of Leaves on Reflectance of Sandy Soil (Cary 90 - Recording Spectrophotometer)

Fig. 3

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2. Materials or Phenomenon Yielding Black Body Spectral Responses

The spectral range of the IRIS does not include the region in which signatures have been reported for organic or biological materials. Indeed, it seems probable that the very materials of paramount interest to us characteristically yield black body responses. Other materials and conditions producing or tending toward a black body response are shown in Table I. This list is based on our results and on additional data and information obtained from conversations with Dr. Hovis. As can be seen, a black body response is not unique to materials with biological implications. In addition, Dr. Hovis mentioned that a large variety of inorganics from reagent bottles, such as potassium nitrate, produce black body responses in the range of the IRIS.

3. Development of a Strategy from Surface Data

Since a variety of materials and phenomenon produce a black body response, the identification of biologically relevant surface material must lie in a strategy of comparison and elimination. One possibility for obtaining biological information from surface spectra lies in the possible universal distribution of reststrahlen-producing SiO_2 on the surface of Mars. Assuming the distribution of SiO_2 is uniform on the Martian surface, any abrupt spatial or temporal changes whereby the SiO_2 signal is either reduced or eliminated could be attributed to

Table I

Materials Producing or Tending Toward a Black Body Response in the IRIS Range

Organic Matter
Biological Matter
Liquid or Solid Water
Any finely divided material (as the material becomes smaller, the reststrahlen effect is reduced accordingly) such as dust
Deviations from flatness (such deviations tend to reduce the extent of the reststrahlen effect)

quench by one of the items cited in Table I. It is of interest to note one other way in which the infrared spectrum of SiO_2 can be altered by phenomenon of biological relevance. It was recently reported[1] that the microorganism, Penicillium simplicissimum, can attack a variety of rock types and, by producing acid, can solubilize a variety of minerals from the rock, including silicates. This fungal attack and solubilization of the rocks actually resulted in an altered infrared spectrum in the silicon-oxygen vibration region.

Since both biological and non-biological materials and phenomenon will alter, reduce, or quence SiO_2 reststrahlen, the likelihood of making biological inferences from surface phenomenon depends on the elimination process. By correlating our data with those obtained from the UV spectroscopy, imagery, and IR radiometry experiments, it may be possible to determine whether observed black body responses came from such surface features as water, ice, or deviations from flatness. Further, the fineness of the surface material may be determined by microwave or other means. This knowledge could reduce the possible causes to organic or biological material. Further distinction between organic and biological material, however, may not be possible. Either, however, would be of biological significance.

4. Probable Distribution of SiO_2 on the Surface of Mars

The strategy outlined above depends upon a uniform distribution of SiO_2 over the surface of Mars. Considerations of distribution of elements in the universe and extrapolation from the two planetary samples which have been examined (Earth and the Moon) tend to support this hypothesis. Indeed, the "official" NASA engineering model of Mars presumes the surface material of Mars to be similar in composition to that of the moon.

Further information on this subject was obtained on March 31, 1971 when Dr. Straat met with Dr. Rudy Hanel and Dr. S. I. Rasool, a geophysicist from the Institute of Space Studies in New York, at Goddard Space Flight Center to discuss the relative distribution of SiO_2 on the Earth, the Moon, and on Mars. Dr. Rasool has studied the relative distribution of elements in the universe [2] and is considered to be an expert in the field of planetary research. According to Dr. Rasool, planets consist mainly of oxygen, silicon, and iron although the ratio of these elements on different planets is not necessarily constant. The density of any given planet depends upon the iron/silicon ratio. The higher density of the planet, the higher the percentage of iron. Thus, dense Mercury consists of 50 percent iron whereas less dense Earth consists of only 30 percent iron. Mars, which is less dense than Earth, will contain an even smaller amount of total iron, and, hence, presumably a larger proportion of silicon.

Regarding the surface distribution of silicon, the amount on the surface relative to the amount throughout an entire planet reflects the geological history of the planet. Earth, for example, differentiated on cooling and the heavier elements, such as iron, concentrated in the center core while the lighter elements, such as silicon, remained in the crust. Thus, on Earth, while the average percentage of silicon throughout the planet is 15.2 percent, the percentage in the crust is 27.7 percent. Correspondingly, the iron content of the core is 100 percent but only 6 percent in the crust. Accordingly to Dr. Rasool, if Mars did not differentiate, the distribution of silicon on the Martian surface would be the same as that throughout the planet body. This value may be about 15 percent (similar to Earth), or perhaps more than 15 percent since Mars is less dense than Earth. On the other hand, if Mars has differentiated, the percentage of silicon on the surface will be considerably higher. However, at present, this issue cannot be resolved. In this regard, it is of interest to note that iron is relatively abundant on the surface of Mars and is probably responsible for the red color of the planet. The distribution of silicon on the Moon, on the other hand, would be governed by an entirely different set of factors. Since the surface of the Moon is constantly bombarded by meteorites. Dr. Rasool believes that the silicon content of the surface of the Moon would reflect that of meteorites, namely 17 percent. (See ref. 3 for further details).

The above discussion concerns the element silicon. The amount of silicates present, on the other hand, reflects the amount of oxygen present. On Earth, silicates are the most abundant components and represent about 60 percent of the crust material. Further, the total amount of silicates throughout Earth is 15 percent, indicating that oxygen is abundant on Earth even in the core of the planet. However, the amount of oxygen on Mars is completely unknown; and, consequently, it is not known how much of the available silicon is present as silicate. It should be noted that the fact that little or no oxygen exists in the Martian atmosphere does not imply that oxygen is not abundant in the Martian crust.

With regards to the uniformity of distribution of silicates on the Martian surface, both Dr. Rasool and Dr. Hanel concur that it is unlikely that silicon distribution will be uniform. The existence of areas of different elevation, of different texture, and of different degrees of darkness indicates considerable lack of homogeneity in the Martian surface. Both crust movements and erosion have undoubtedly contributed to heterogeneity of the silicon distribution on the Martian surface. Thus, they anticipate a non-uniform distribution of silicon on Mars as on Earth.

5. Status of Obtaining Biological Inferences from Surface Phenomenon

At the moment, it is doubtful that biological inferences can be made from surface reflectance spectra of Mars. Our results suggest that the material of biological or organic origin characteristically

yields a black body response in the range of the IRIS. Unfortunately, a black body response is not unique to materials of biological relevance. It appears that the best hope for obtaining information of significance for biology is to follow the characteristic reststrahlen effect of SiO_2 which would show up clearly in the IRIS window around 10μ. Reduction or disappearance of this signal may reflect quench by biological material similar to the results described in Figures 2 and 3. The success of this strategy lies in the reliability of the elimination of the other non-biological factors which typically yield black body responses and on the uniformity of silicate distribution over the Martian surface. Since successful elimination appears improbable and since uniform SiO_2 distribution seems unlikely, the chance of success for this strategy appears remote. Nonetheless, the Martian SiO_2 surface distribution will be mapped by the IRIS. Should this distribution be more uniform than currently anticipated, and otherwise unexplained interruptions encountered, such a strategy may become valuable for making biological inferences.

It does appear, however, that one valuable piece of interential information will be obtained from the IRIS regarding surface phenomenon of biological interest. The pressure and temperature measurements to be made on the Martian surface will make it possible to determine whether or not liquid water can exist on Mars. Such information is extremely relevant to decide whether or not it appears possible for life

to exist on Mars. Further, if liquid water were limited to only certain locations on the Martian surface, this finding probably would influence the selection of the landing site for the Viking Mission of 1975.

B. Inferences to be Made from Atmospheric Analysis

The probability of obtaining biologically relevant information from analysis of the constituents of the Martian atmosphere is considerably higher than from surface phenomenon. The IRIS offers high promise of detecting atmospheric gases by characteristic signatures. Therefore, we have placed our major emphasis on preparing a list of biologically important gases for which signatures would be established prior to analysis of the IRIS data. In addition, we have examined a variety of ways in which detection of trace gases can imply life processes.

1. Gases Involved in Terrestrial Metabolic Pathways [4-17]

Ultimately, the energy derived for continuing life processes must come from the sun [7], implying a photosynthetic reaction for energy fixation. On Earth, the photosynthetic fixation of carbon dioxide by green plants in the presence of light proceeds as follows:

$$(1.)\quad 6CO_2 + 6H_2O + 674\ \text{KCal} \underset{\text{Respiration}}{\overset{\text{Assimilation}}{\rightleftharpoons}} C_6H_{12}O_6 + 6O_2$$

The reverse reaction, respiration, occurs in most heterotrophic organisms. Variations of this photosynthetic reaction are known to occur. For example, certain anaerobic purple sulfur bacteria perform the following photosynthetic reactions:

(2.) $CO_2 + 6H_2S + 295.6\ KCal \longrightarrow C_6H_{12}O_6 + 3O_2 + 3/4\ S_8$
(Chlorobacteriaceae, thiorhodaceae)

(3.) $CO_2 + C_3H_7COOH + H_2O \longrightarrow 5(CH_2O)$

While these are the only known photosynthetic processes on Earth, other photosynthetic reactions are possible[8]:

(4.) $6CH_4 + 6H_2O + 214.5\ KCal \longrightarrow C_6H_{12}O_6 + 12H_2$

(5.) $6CO_2 + 12H_2O + 1280\ KCal \longrightarrow 6CH_4 + 12O_2$

Reaction (4.) allows a life process corresponding to (1.) to occur in a reducing atmosphere. Reaction (5.) is hypothetically possible on Mars and provides an even better energy lift than the two processes known on Earth. It has the disadvantage that the resulting methane is not particularly reactive for further metabolic pathways. In summary, the biologically important gases involved in these processes are: CO_2, O_2, H_2O, H_2S, CH_4, and H_2.

Several gases are involved in biological pathways concerned with nitrogen metabolism[9, 10]. Nitrogen fixation, the process by which atmospheric nitrogen gas is converted to organic form, is accomplished by several microorganisms including Azotobacter, Clostridium pasteuranium, blue-green algae, and by legumes living symbiotically with Rhizobium. Nitrogen gas is also known to be a metabolic end product of anaerobic nitrite or nitrate reduction by denitrifying bacteria such as Pseudomonas aeruginosia, Bacillis subtilis, and

Micrococcus denitrificans. Other denitrifying bacteria are known which produce instead the gases N_2O or NO as end products. One unusual denitrifying bacteria is Thiobacillus denitrificans which produces nitrogen gas according to reaction (6).

$$(6.)\quad 5S + 6HNO_3 + 2H_2O \longrightarrow 5H_2SO_4 + 3N_2$$

In addition to these three nitrogen containing gases, ammonia is also involved in biological pathways. The chemoautotrophic soil bacteria Nitrosomonas derives energy by the aerobic oxidation of ammonia to nitrite as in reaction (7.).

$$(7.)\quad NH_3 + 3/2\ O_2 \longrightarrow HNO_2 + H_2O$$

With other microorganisms, ammonia is an end product resulting from the decay and decomposition of urea and plant, animal, and microbial proteins. Thus, in addition to the previously mentioned gases, N_2, N_2O, NO and NH_3 are also biologically important.

Of the gases involved in sulfur metabolism[4], hydrogen sulfide is utilized both photosynthetically (Reaction 2) and non-photosynthetically by oxidation by the sulfur bacteria Beggiatoa alba:

$$(8.)\quad 2H_2S + O_2 \longrightarrow 2H_2O + 2S$$

Hydrogen sulfide is also produced by sulfate reducing bacteria such as Desulfovibrio desulfuricans (Reaction 9) and Sporovibrio (Reaction 10). These bacteria are strict anaerobes.

(9.) $2CH_3\,CHOH\,COONa + H_2SO_4 \longrightarrow 2CH_3COONa + H_2S + 2CO_2 + 2H_2O$

(10.) $4H_2 + H_2SO_4 \longrightarrow H_2S + 4H_2O$

With Desulfovibrio desulfuricans, the production of sulfur monoxide (S_2O) has also recently been noted and it is postulated that this gas may be an intermediate in the reduction of sulfate[11]. Thus, in addition to the above gases, sulfur monoxide is also of biological importance.

Carbon monoxide is an additional gas of biological implications. It is readily produced non-biologically by the photochemical reaction:

(11.) $CO_2 \longrightarrow CO + O$

Carbon monoxide is also known to be produced metabolically in large quantities by brown kelp, marine algae[12, 13], the Portuguese man-of-war[14], and some siphonophores[15]. Reoxidation of carbon monoxide to carbon dioxide as in reaction (12.) is known to provide an energy source for both B. oligocarbophilis and Carboxydomonas.

(12.) $CO + 1/2\,O_2 \longrightarrow CO_2 + 74\ KCal$

It has been postulated[7, 16] that such a reoxidation could provide an energy source for Martian life if the reaction were coupled to sulfite reduction as has been observed in cell-free extracts of Desulfovibrio[17]:

(13.) $H_2SO_3 + 3CO \longrightarrow 3CO_2 + H_2S$

In addition to the hypothetical reactions (4 and 5), methane is also known to be both utilized and produced by terrestrial

microbes. Thus, methane is produced in one bacterium according to the following reactions:

(14.) $4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O$

(15.) $4HCOOH \longrightarrow CH_4 + 3CO_2 + 2H_2O$

It is likewise utilized by B. methanicus according to reaction (16.).

(16.) $CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$

The final gas to be considered is hydrogen which is known to be utilized by a variety of microbes according to the following reactions:

(17.) $2H_2 + CO_2 \longrightarrow HCHO + H_2O$ (green alga Scenedesmus)

(18.) $2H_2 + O_2 \longrightarrow 2H_2O$ (Hydrogenomonas)

(19.) $4H_2 + SO_4^{=} \longrightarrow S^{=} + 4H_2O$ (Sporovibrio desulfuricans)

(20.) $4H_2 + NO_3^{-} \longrightarrow NH_3 + 2H_2O + OH^{-}$

(21.) $4H_2 + 2CO_2 \longrightarrow CH_2COO^{-} + H_2O + H_3O^{+}$ Clostridium

(22.) $4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O$

The enzyme responsible for hydrogen utilization is known as "hydrogenase" and this enzyme probably catalyses the reverse reaction under certain conditions. In addition to these reversals, Clostridium butylicum is one of several microbes known to produce hydrogen gas as a metabolic end product[17]:

(23.) $CH_3COCOOH + H_2O \longrightarrow CH_3COOH + CO_2 + H_2$

These, then, comprise the gases known to be involved in terrestrial metabolic pathways: O_2, H_2, H_2O, CO, CO_2, CH_4, H_2S, S_2O, N_2, NO, N_2O, and NH_3. Most of these gases are both utilized and produced metabolically. It is of interest to note in passing that many of the reactions which utilize a particular gas also produce another gas as an end product. In addition to these gases, it may be of value to consider such gases as NO_2, N_2O_3, SO_2, and SO_3. While these do not play a significant role in terrestrial metabolism, they could conceivably play a role in extraterrestrial life processes.

2. Gas Detection by the IRIS

On the basis of the foregoing discussion, the gases of biological interest are O_2, H_2, H_2O, CO, CO_2, CH_4, H_2S, S_2O, N_2, NO, N_2O, and NH_3. Other gases of interest include O_3, NO_2, N_2O_3, SO_2, and SO_3. Many of these gases have strong absorption bands in the IRIS range (Table II) with the exception of CO and NO which do not have fundamental bands in this range. Unfortunately, O_2, H_2, and N_2 lack a dipole moment and cannot be studied by infrared spectroscopy. The gases theoretically detectable by the IRIS, then, are H_2O, CO_2, CH_4, H_2S, S_2O, N_2O, NH_3, O_3, NO_2, N_2O_3, SO_2, and SO_3. Of these, H_2O, CO_2, CH_4, H_2S, N_2O, NH_3, and O_3 are considered most important.

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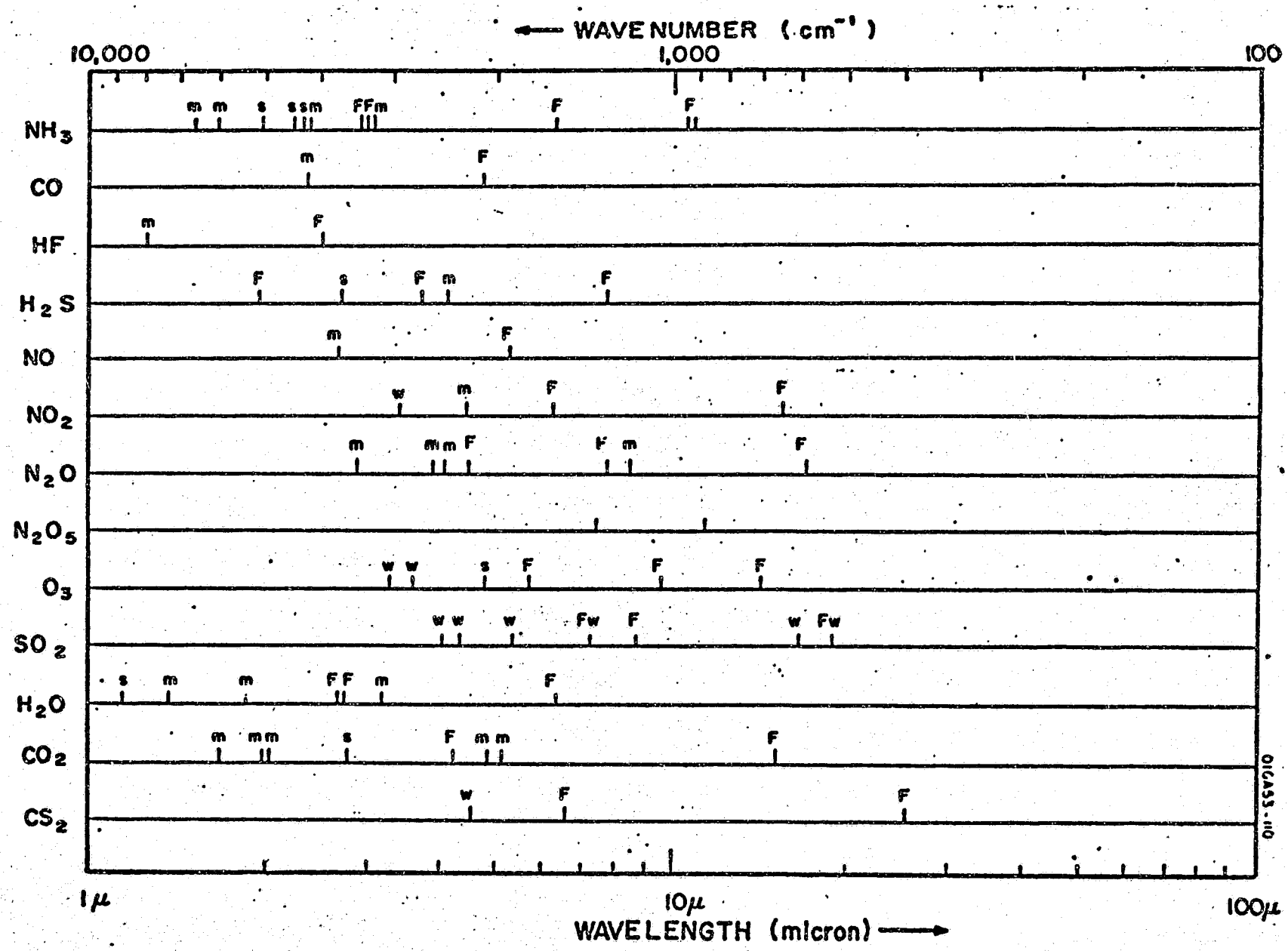
Table II



Absorption bands of several gases. Strength of absorption is indicated by following notation. F-fundamental (very strong); m-medium; w-weak. (from Herzberg, G., 1950: Molecular Spectra and Molecular Structure. van Nostrand, 632 pp).

3. Gases Detected in the Earth's Atmosphere

Table III presents the concentration of the gaseous components of the Earth's atmosphere. As shown, many of these components are biologically significant. In addition to these gases, a variety of hydrocarbons have also been detected in our atmosphere [18], as mentioned above.

Most of the gases shown in the preceding section of this report to be biologically significant are found in our atmosphere to varying extents. However, these gases also reflect processes other than metabolic activity. Thus, CO results from photochemical dissociation of CO_2, O_3 arises from O_2 by the action of electrical discharges, nitrogen gases result from volcanic action [21], and hydrocarbons arise from deep oil wells. The gases H_2 and CH_4 may be remnants from the early reducing atmosphere believed to be associated with the origin of the planets [22]. Many other gases, including O_2, H_2, and N_2O, are also produced non-biologically [19, 23]. Oxygen, for example, is produced in the upper atmosphere by the photolysis of water although it is primarily a biological product.

4. Relationships Between Atmospheric Gases and Surface Metabolic Activity

Because atmospheric components are produced both biologically and non-biologically, the mere detection of a particular component is not conclusive evidence of life processes. Three ways in which gases could reflect a surface bicta are discussed below.

TABLE III

Components of the Earth's Atmosphere [19,20]

Component	Content (%)	Metabolic Significance
N_2	78	Yes
O_2	21	Yes
CO_2	$3x10^{-2}$	Yes
A	$9x10^{-1}$	No
Ne	$18x10^{-4}$	No
He	$5x10^{-4}$	No
Kr	$1x10^{-4}$	No
Xe	$9x10^{-6}$	No
H_2O	1 to 10^{-3}	Yes
H_2	$5x10^{-5}$	Yes
CH_4	$2x10^{-4}$	Yes
N_2O	$5x10^{-5}$	Yes
CO	$5x10^{-6}$	Yes
O_3	10^{-5} to 10^{-6}	Yes
NO, NO_2	$5x10^{-8}$ to $2x10^{-6}$	Yes

a. Diurnal Fluctuations in Gas Concentrations

It may be possible to detect a diurnal fluctuation in the concentration of a particular gas. Such fluctuations in CO_2 concentration have, in fact, been detected by IR scanning over heavy foliage. Fluctuations such as these may be expected for any life system whose energy is ultimately derived from the sun.

b. Isotopic Ratios of Elements

Isotopic ratios of elements which have natural isotopes may also provide evidence of metabolic processes. Planetological processes have long since reached an equilibrium with respect to isotopic ratios. Biological processes, however, continuously enrich these ratios with the lighter isotope by virtue of mass kinetics. For example, the dissimilatory reduction of sulfate by Desulfovibrio desulfuricans fractionates the isotopes of sulfur, resulting in an enrichment in the ^{32}S content of reduced sulfur compounds. Since this biological process is the only process known to fractionate these isotopes, a high ratio of $^{32}S/^{34}S$ has been taken as evidence of life[24]. Similar examples may be cited regarding other elements. Thus, evidence of life could be obtained by observing differences in the isotopic ratio in a particular compound at different points along the surface or at the same point at different times of the diurnal cycle. Alternatively, as pointed out by Hitchcock and Lovelock[19], when a particular element exists in more than one atmospheric component, differences in the isotopic ratio

among these components would imply a metabolic process. For example, if different $^{14}N/^{15}N$ ratios were found in N_2 and N_2O, the difference may result from metabolic enrichment in the ^{15}N content of only one of these gases. Likely candidates for such isotopic analysis in gases are carbon and nitrogen compounds. Unfortunately, although isotopes do differ somewhat in absorption properties[25], the resolution power of the IRIS may not be sufficiently high to detect concentration differences among isotopes of the same element.

c. The Hitchcock/Lovelock Theory

A theory for the detection of life by atmospheric analysis has recently been presented by Hitchcock and Lovelock[19,23]. The assumption behind this theory is that the entropy of living systems is low relative to that of their nonliving environments. Consequently, living systems will drive their environments into physical or chemical disequilibrium and there will always exist an entropy gradient between living systems and their nonliving environments. Thus, the significance of a particular atmospheric component for life processes lies in a discrepancy between its existing concentration and that expected from its non-biological reactions. The following examples taken from the Earth's atmosphere are cited:

- The simultaneous presence of H_2 and O_2 implies that they are continuously produced from the surface.

- The simultaneous presence of CH_4 and O_2 also implies the biological production of CH_4 at the surface. It is known that methane is irreversibly oxidized by oxygen and that more methane is present in our atmosphere than can be accounted for by the known half-life of methane toward oxidation. The authors mention that this argument may be applicable to Mars unless its atmosphere is partially reduced.

- Both CO and H_2 are produced in the upper atmosphere by photodissociation of CO_2 and H_2O. However, the concentrations of both gases in our atmosphere are too high to be accounted for strictly by non-biological production.

- Oxygen is also produced non-biologically by the photolysis of water in the upper atmosphere. However, the concentration present in our atmosphere is considerably greater than can be accounted for by this non-biological process.

- The gas N_2O is short lived due to its rapid destruction by long UV radiation. Thus, its existence in our atmosphere suggests that it is constantly replenished biologically.

It is possible that similar discrepancies in gas concentrations in the Martian atmosphere may imply surface biota. Further, if a vertical concentration profile could be obtained for each component, this information would be quite valuable in determining where a gas is produced and where it is removed.

d. Limitations of IRIS in Utilizing Theories to Make Biological Implications

Regarding our studies related to the composition of the Martian atmosphere, it is unlikely that the IRIS is sufficiently sensitive

to detect gas concentration gradients or diurnal fluctuations in gas concentrations. Further, although it may be possible to detect the presence of various isotopes, the detection will probably not be sufficiently refined to determine differences in the isotopic ratios of various elements as a function of time or location. Thus, while the IRIS data will allow calculation of a $^{12}C/^{13}C$ atmospheric ratio, the error in this determination will probably be so large that fluctuations in this ratio with time or distance variation cannot be detected. The IRIS can, however, yield biological information if sufficient information can be gleaned on Mars atmospheric photochemistry. Anomalies in the atmospheric constituents which will be detected by the IRIS would then be indicative of constant replenishment or utilization at the surface of Mars. Hopefully, other data to be obtained from the Mariner Mars '71 would supply the necessary information to distinguish between biological replenishment and non-biological replenishment (as from a volcano) of a particular gaseous constituent. Particularly pertinent to our study of atmospheric photochemistry are the review articles by Cadle and Allen[26] and by Donahue[27].

5. Presence of Hydrocarbons and Related Derivatives in the Earth's Atmosphere

a. Comments on "Blue Haze"

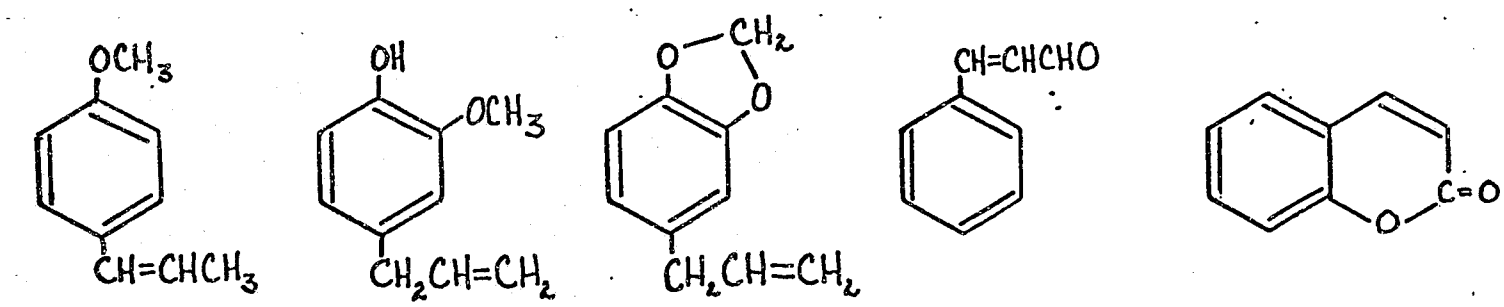
A so-called "blue haze" has been postulated to exist as either an absorbing or scattering atmospheric layer around Mars. Although the existence of this haze is quite controversial[28], it is not impossible that such a layer could be of considerable biological significance.

Relevant to this concept are several articles published by F. W. Went[29-31]. Sent commented on the existence of a blue haze often seen in the Earth's atmosphere and hypothesized that it may be due to the presence of naturally occurring hydrocarbons. According to Went, a variety of volatile organic substances is produced from various types of vegetation such as meadows and sagebrush. The fragrance of a pine forest, for example, results from the production of the volatile terpene, pinene. In model experiments cited by Went, a blue haze resulted when volatile organics (petrol and olefine) were mixed with ozone, or when terpenes, pine needles, or other aromatic plant material were placed in an ozone-containing atmosphere. Other gases, such as nitrogen oxides, are also capable of catalyzing olefin oxidation in the presence of light energy. While it is not yet known whether traces of oxidizing gases exist in the Martian atmosphere, it is of interest that oxygen and ozone have been tentatively identified by Belton and Hunten[32] and by Barth, et. al.[33]. Thus, the Martian "blue haze phenomenon" could reflect the presence of hydrocarbons which in turn may be biologically produced. These facts have directed us toward an investigation of terrestrially pertinent hydrocarbon end products.

b. Terpene End Products on Earth

Terrestrial land plants produce approximately 10^8 tons of volatile organic compounds annually[29-31]. These products may be separated from plant material by steam distillation and are known as

"essential oils". They are generally regarded as waste products of plant metabolism and are highly aromatic, giving the characteristic odor and flavor of plant parts such as fragrant flowers, mint leaves, cinnamon bark, clove buds, sandalwood, nutmeg seeds, and pine needles. The fragrance of meadows, sagebrush and other types of vegetation of dunes and semi-arid regions is due to such volatile organic substances. Many of these products are economically important in perfumes, cosmetics, flavoring, varnishes, and medicines. Common aromatic examples include anethole (anise oil), eugenol (oil of cloves), safrole (oil of sassafras), and cinnamaldehyde (oil of cinnamon). Coumarin has been isolated from many plants and is responsible for the order from newly mown hay.



ANETHOLE EUGENOL SAFROLE CINNAMALDEHYDE COUMARIN

Many essential oils are hydrocarbons, especially terpenes and their oxygenated derivatives. Terpenes, composed of isoprene units (C_5H_8), are of the following composition:

$C_{10}H_{16}$ = Monoterpenes

$C_{15}H_{24}$ = Sesquiterpenes

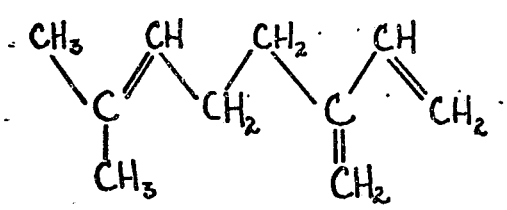
$C_{20}H_{32}$ = Diterpenes

$C_{30}H_{48}$ = Triterpenes

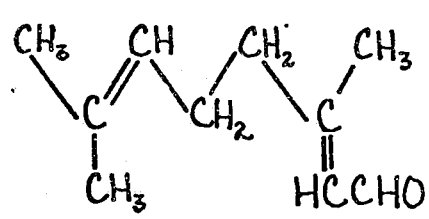
$C_{40}H_{64}$ = Tetraterpenes

Of these, only monoterpenes and sesquiterpenes and their oxygenated derivatives can be obtained by steam distillation. They are widely distributed in nature and hence of greatest interest. Di- and triterpenes are neither volatile nor widely distributed; tetraterpenes are more common and include carotenoids.

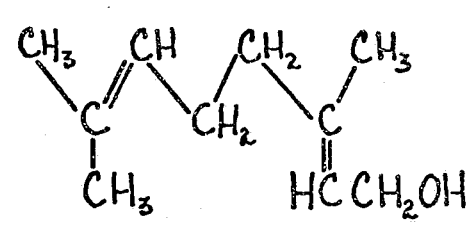
Monoterpenes may be either acyclic, monocyclic, or dicyclic in structure. Acyclic monoterpenes are abundant in exudates of conifers and in oils from citrus fruit and from eucalyptus trees. Common acyclic monoterpenes include the hydrocarbon myrcene (from oil of bay), the aldehyde citral (oil of lemon grass), and the corresponding alcohol geraniol (from rose oil and ginger grass). Each of these is quite important and widely distributed among plants.



MYRCENE



CITRAL

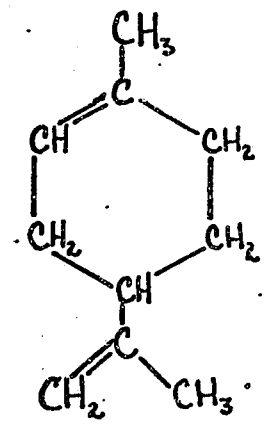


GERANIOL

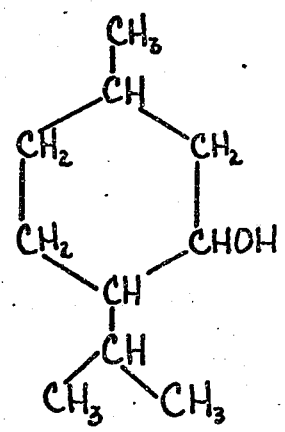
Other acyclic monoterpenes indude nerol (orange blossom oil), citronellal (oil of citronella), and linalool (oil of a Mexican sood and of flowers of the Philippine ylang-ylang tree).

The most important monocyclic monoterpene is the hydrocarbon limonene. This terpene is the main constituent of oil of lemon, orange, carraway, dill, bergamot and others. With the possible

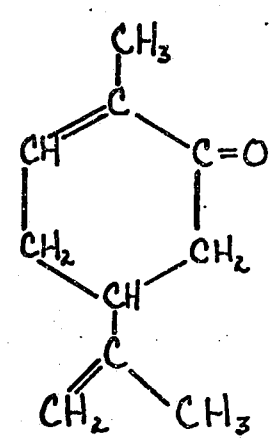
exception of α-pinene, no terpene is present in more varieties of plants. Common oxygenated derivatives of limonene include menthol (mint oil) and carvone (spearmint oil).



LIMONENE

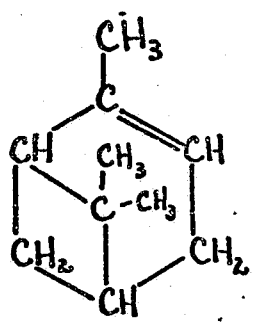


MENTHOL

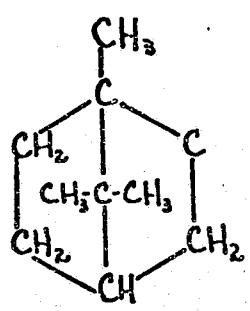


CARVONE

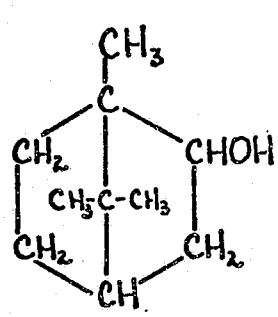
Of the dicyclic monoterpenes, the hydrocarbon α-pinene is perhaps the most widely distributed of all terpenes. This terpene is derived from pine trees and is the main constituent of oil of terpentine. Other common dicyclic monoterpenes include d-camphor from the wood of the camphor tree Cinnamomum camphora, d-borneol from hemlock oil, and d-Δ^3-carene from pine needle oil.



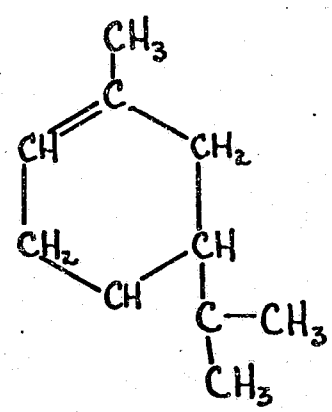
α-PINENE



d-CAMPHOR

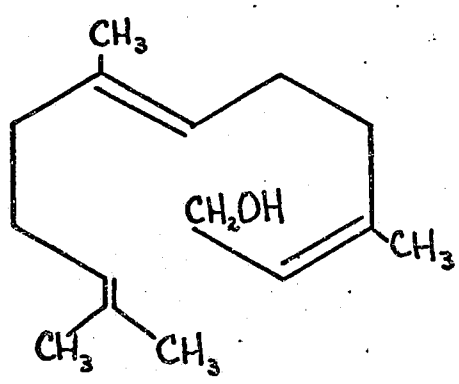


d-BORNEOL

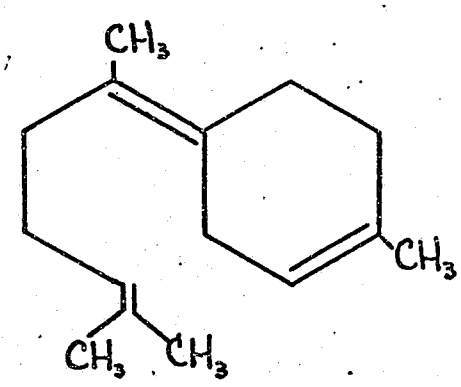


d-Δ^3-CARENE

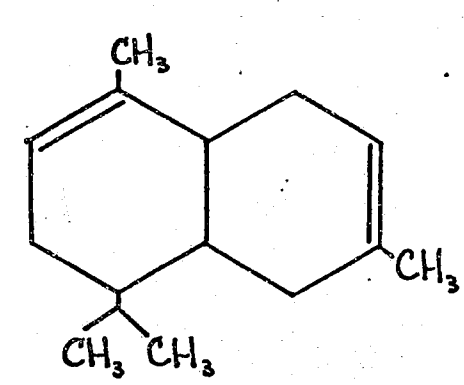
The final category of volatile terpenes to be considered are the sesquiterpenes, composed of three isoprene units. The best known example is the acyclic compound farnesol which is widely distributed among plants but found in small amounts. A monocyclic sesquiterpene that occurs in many plants is bisabolene, a hydrocarbon made from the dehydration of farnesol. Examples of dicyclic sesquiterpenes are cadinene (from Juniperus oxycedrus), β-selinene (oil of celery), and eudesmol (eucalyptus oils)[34-36].



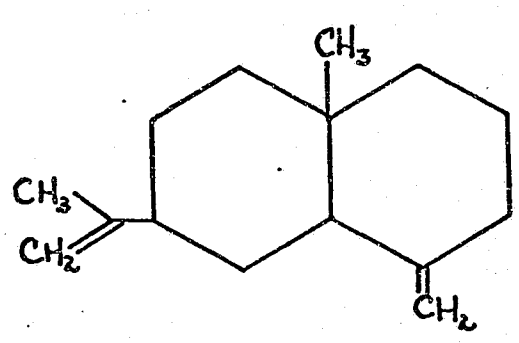
FARNESOL



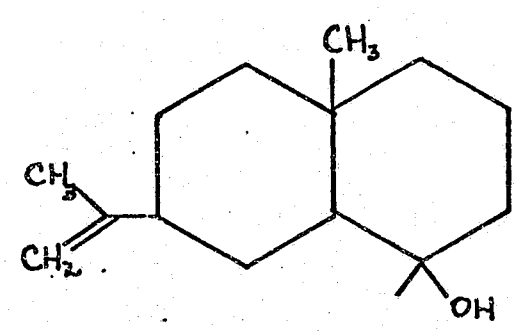
BISABOLENE



CADINENE



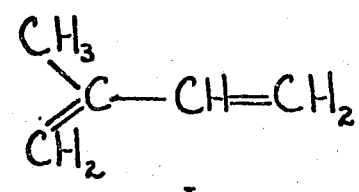
β-SELINENE



EUDESMOL

In addition to terpenes, the hemiterpene isoprene has recently been reported to be present both in natural plant products and in the atmosphere over foliage areas[37]. This compound, in fact, has a

frequency of occurrence similar to that of α-pinene and, consequently, is of major importance as a volatile plant product.



ISOPRENE

These volatile organic compounds, then, comprise some of the major compounds which have been derived from the essential oils of plants. As a final illustration of how widespread is the occurrence of terpenes in plants, Table IV shows the number of known species in which each of several monoterpenes occurs[38]. As shown, α-pinene is by far the most prevalent compound. It should be noted, however, that this table was compiled before the discovery of isoprene as an end product and that current indications are that isoprene is at least as common as α-pinene[37].

c. Detection of Terpenes on Mars

The anticipated Martian atmosphere consists of a mixture of carbon dioxide and up to 25 precipitable microns of water. A theoretical spectrum of this mixture (using ten precipitable microns of water) was constructed at GSFC and clearly reveals a large spectral "window" existing between 800 and 1300 wavenumbers. That terpenes do absorb in the range of the IRIS is shown in Figure 4 by the absorption spectrum of camphor[39]. As seen, prominent bands occur within the large spectral window (800 - 1300 wavenumbers) expected for the Martian

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TABLE IV

Number of Species in Which Each of the Following Monoterpenes has Been Identified[38]

Monoterpene	No. Species
α-pinene	412
cineole	218
limonine	272
phellandrene	152
geraniol	123
borneol	108
linalool	96
α-terpineol	86
camphene	85
ρ-cymene	71
citral	67
β-pinene	67
camphor	62
thymol	43
carvacrol	40
terpinene (α, β)	36
citronellol	33
piperitone	33
menthol	32
menthone	30
pulegone	27
citronella	26
thujone	24
sabinene	22
carvone	16
myrcene	16
terpinenol	14
carene (Δ^3-, Δ^4-)	11
methyl heptenone	11
thujyl alcohol	11
ocimene	10
dihydrocumic alcohol	9
fenchone	8
peperitol	8
fenchyl alcohol	6
fenchene	4
methylheptenol	4
pirillaldehyde	4
terpinolene	4

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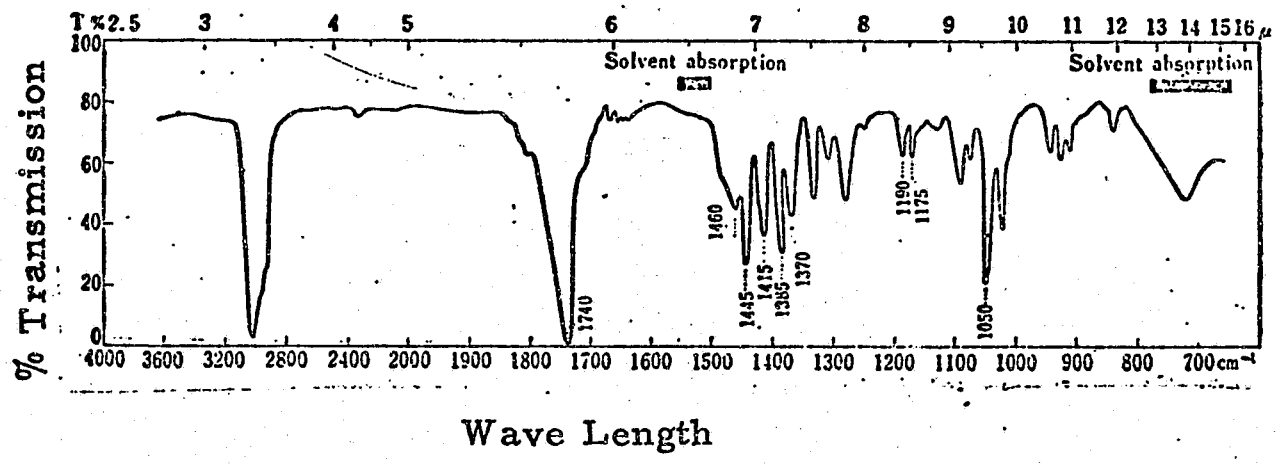

Spectrum of camphor obtained in CCl_4 Solution in a 0.5 mm cell. Taken from Nakanishi [39], p. 91

Title	Infrared Absorption Spectrum for the Monoterpene Camphor
	Fig. 4
BIOSPHERICS INCORPORATED Rockville, Maryland	Date / Init. / Scale
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atmosphere. Likewise, strong absorption bands occur for isoprene at 990, 908, and 895 wavenumbers [37].

Figure 5 shows the relationship between temperature and vapor pressure for each of these terpenes. Knowing the Martian temperature and the minimum amount detectable by the IRIS, we can establish which of these compounds could be discerned in the Martian atmosphere. As seen in Figure 5, the compound most likely to be detected is isoprene whereas that least likely is farnesol. Vapors from these compounds would not escape from the Martian atmosphere because their molecular weights are all greater than that of carbon dioxide which is known to be captured by the Mars gravitational field. Isoprene, the smallest compound, has a molecular weight of 68.

The detection of a terpene in the Martian atmosphere would be highly indicative of life processes. On Earth, direct measurement of the volative organics in the atmosphere show that an average concentration of 10×10^{-9} (10 ppb) exists in the air [31]. Higher localized concentrations have been reported. Thus, the concentration of isoprene alone over Mango foliages in Panama has been measured [37] at 0.5 to 24 ppb. The concentration of all terpenes combined over a particular area can be considerably higher. Detection of a terpene on Mars would be especially significant if its presence were found to vary spatially. Spatial variation in both type and concentration would be expected on Earth where foliage

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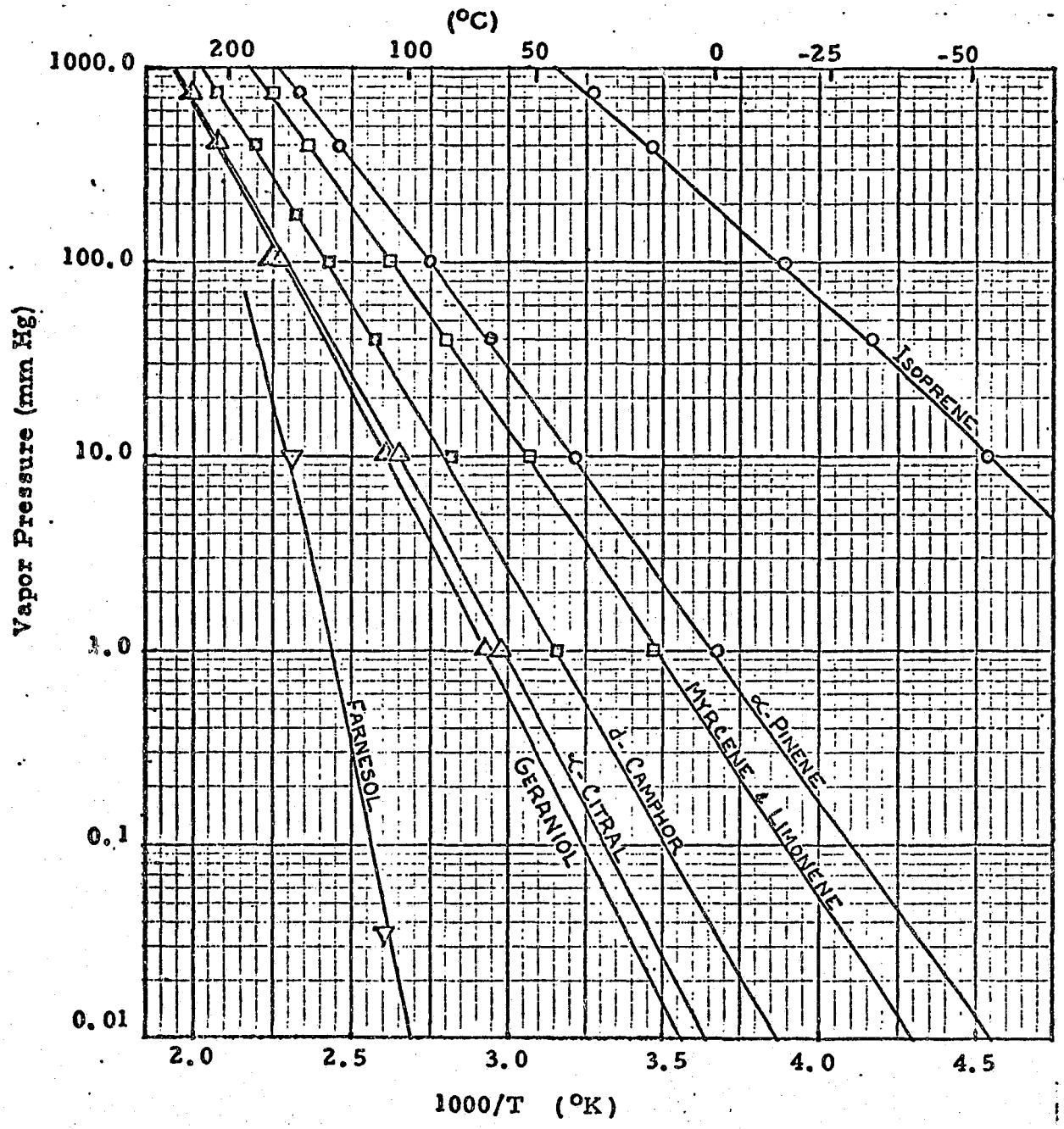

Plotted from Data in Handbook of Chemistry and Physics, 47th Edition and The Merck Index, 8th Edition.

Title: Relationship Between Temperature and Vapor Pressure for Several Terpenes	
BIOSPHERICS INCORPORATED, Rockville, Maryland	Fig. 5
	Date / Init. / Scale
Cont. No.	Report Title: IRIS Biological Experiments

areas are not uniform. Further, Rasmussen and Went[31] have reported seasonal variation in volatile organics over country and forest air from 10^{-8} in the summer to 2×10^{-9} (2 ppb) in the winter.

While terpene concentrations are not particularly high in the Earth's atmosphere, these concentration levels do not reflect possible levels on Mars and their abundance in terrestrial metabolism warrents their study. (It should be mentioned that numerous cyclo pentanoid monoterpenes are also found in the terrestrial insect kingdom[38].) Thus, it seems important to establish signatures at lease for those terpenes most common and abundant terrestrially. Those recommended for study are: isoprene, α-pinene, myrcene, citral, geraniol, limonene, camphor, and farnesol. Because of their widespread abundance, isoprene and α-pinene are probably the most important compounds on this list. Further, it might be of considerable value to study these compounds both in the form of gases and in the form of submicroscopic particles formed by reaction with ozone ("blue haze").

6. Current Knowledge of Gas Constituents on Mars

a. Gases Detected or Postulated in the Martian Atmosphere

The Martian atmosphere consists almost entirely of carbon dioxide. Water vapor and carbon monoxide are the only other constituents which have been positively identified[25] in the Martian atmosphere and both are present only in small amounts. Thus, the amount of

water vapor present averages to only about 15 precipitable microns. Carbon monoxide undoubtedly arises, at least in part, from the photolysis of carbon dioxide. Oxygen is also expected to be present in the atmosphere as a result of this reaction and, in fact, has been tentatively identified in the Martian atmosphere [32, 33]. A recent report has also suggested that nitrogen gas may be present to the extent of 0.5 to 5 percent of the total carbon dioxide content [40].

In addition to these gases, other minor constituents have been sought and the upper limits of abundances have been established for a variety of possible constituents. These upper limits are shown in Table V [25].

b. Organic Compounds Formed in a Simulated Martian Atmosphere

A recent paper by Hubbard, Hardy, and Horowitz [41] describes an experiment in which CO_2, CO, and water vapor are mixed and irradiated with ultraviolet light in the presence of soil (simulated Martian conditions). The three organic compounds tentatively identified as the main products of this reaction are formaldehyde, acetaldehyde, and glycolic acid. Thus, it seems highly possible that these compounds may exist on the surface of Mars. Formaldehyde and acetaldehyde may, in addition, exist in the Martian atmosphere since their boiling points are -21 and +21°C, respectively. The higher melting point of glycolic acid

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TABLE V
(from Ref. 25)

Upper Limits on Abundances for Possible Minor Constituents in the Martian Atmosphere

Molecule	Path Length (cm-atm)	References
O_3	0.004	Belton and Hunten, 1968
NO	20	Kuiper, 1964
NO_2	0.0008	Marshall, 1964
N_2O	0.08	Kuiper, 1964
NHO_2	0.16	Sagan, Hanst, and Young, 1965
HCHO	0.3	Kuiper, 1964
COS	0.2	Kuiper, 1964
H_2S	7.5	Kuiper, 1964
CH_4	0.1	Kuiper, 1964
C_2H_4	3	Kuiper, 1952
C_2H_6	1	Kuiper, 1952
NH_3	0.1	Kuiper, 1964

(α 63°; β 79°C) makes it less likely that this compound would be present in the Martian atmosphere.

7. Status of Obtaining Biological Inferences from Atmospheric Analysis and Recommended List of Gases for Signature Study

The IRIS experiment will be quite able to detect trace constituents of the Martian atmosphere provided their concentrations are sufficiently high. Detection is, in fact, facilitated by large spectral windows created by the absence of large quantities of ozone and water vapor in the Martian atmosphere. For those constituents not detected, the upper limit of abundance will most certainly be lowered.

The mere presence of a trace component is of considerable importance since it provides insight into the evolution of the atmosphere and may also reflect biological activity of the planet. While the presence or absence of a particular constituent does not establish metabolic pathways, it does impose certain restrictions on types of metabolism which are theoretically possible.

To obtain more direct evidence for metabolism, it would be necessary for the IRIS to detect fluctuations in gaseous concentrations or in isotopic ratios which occur either with temporal or spatial variation. Vertical gaseous concentration gradients could also be indicative of life processes. While it is not impossible that such information will be obtained, this type of evidence is not likely to be found by the IRIS. Alternatively, establishment of the presence or absence of a gas, coupled

with a thorough knowledge of atmospheric photochemistry, could indicate anomalies in the concentration of that gas. This, in turn, would be indicative of continued utilization or replenishment of the gas, perhaps by metabolic processes. It is by this approach that the IRIS experiment has the highest probability of detecting metabolic processes. Further distinctions between metabolism and such non-biological gas evolving processes as volcanoes could undoubtedly be made from additional data to be obtained by Mariner Mars '71.

Because of the high probability of the IRIS detecting trace components in the Martian atmosphere, it is necessary to establish infrared absorption signatures for possible Martian atmospheric constituents. On the basis of the studies reported herein, we have prepared a list of gases and organic compounds for which we feel signatures should be established. The complete list is shown in Table VI along with recommended priorities for each. Of the gases we have selected for signature study, O_3, H_2O, CO_2, CH_4, H_2S, N_2O, and NH_3 are considered imperative. Since NO_2, N_2O_3, SO_2, S_2O, and SO_3 do not seem to play a significant role in terrestrial metabolism, they have been relegated to a position of lower priority. Signatures for a variety of hydrocarbons should also be established. Since many terpenes are found in the Earth's atmosphere, it would be of value to establish signatures for those most common. Such compounds, if merely detected in the Martian atmosphere, would be indicative of life

TABLE VI

Gases and Organic Compounds Recommended for Signature Study

1st Priority	2nd Priority	3rd Priority
O_3 (O_2)	Formaldehyde	NO_2
H_2O	Acetaldehyde	N_2O_3
CO_2	Isoprene	SO_2
CH_4	α-Pinene	SO_3
H_2S	Myrcene	S_2O
N_2O	Citral	
NH_3	Geraniol	
	Limonene	
	Camphor	
	Farnesol	

processes. In view of the rather large number of these compounds, however, the study should be restricted to the most common and abundant terrestrial examples: isoprene, α-pinene, myrene, citral, geraniol, limonene, camphor, and farnesol. Of these, isoprene and α-pinene are the most important terrestrially. In addition, other organic compounds which may be present in the Martian atmosphere, such as formaldehyde and acetaldehyde, should be characterized.

Signature studies of various trace gases is currently being conducted at the Goddard Space Flight Center. To date, information regarding the signatures of O_3, H_2O, and CO_2 have been obtained and placed on magnetic tape for computer use in the construction of theoretical gas absorption spectra. The gases yet to be placed in the theoretical tape atlas are N_2O, CH_4, and NH_3. In addition to constructing the theoretical tape atlas, a laboratory atlas of various trace gases is also being constructed and will include several of the additional gases which we previously recommended for study. Preliminary absorption spectra have already been obtained on the Cary 90 recording spectrophotometer for NO, N_2O, NO_2, CH_4, NH_3, H_2S, SO_2, CO, CO_2, and N_2O_3. Currently, each of these gases is being re-examined by Dr. Gene Welker on a Perkin Elmer instrument with a longer pathlength (10 meters) and at low pressure. This will improve spectral resolution and will approximate conditions to be seen by the IRIS.

III. CONCLUSIONS

Our investigation concerning possible ways in which biological inferences may be obtained from the Mariner Mars '71 IRIS experiment has encompassed data to be obtained from both surface reflectance and from atmospheric analysis.

Regarding surface phenomenon, the IRIS will be able to determine whether or not it is possible for liquid water to exist on the surface of Mars. This determination is of fundamental importance for considerations of possible metabolic schemes. It is unlikely, however, that surface data will yield additional biological inferences. Our results and those of others indicate that both biological and organic material show a characteristic blady body response in the range of the IRIS. The possibility of inferring biological or organic material by quench of SiO_2 reststrahlen also appears remote, although not impossible. Thus, if the distribution of SiO_2 is uniform on Mars, and if other possible sources of quench can be reliably estimated, then quench of SiO_2 may provide information related to life on Mars.

Atmospheric analysis provides greater hope for obtaining inferential information related to life on Mars. The IRIS is capable of detecting small amounts of trace gases in the Martian atmosphere which would reflect both biological and non-biological processes on the planet. That many of the gases involved in terrestrial metabolism are present in the Earth's

atmosphere has been shown in this report. It should be kept in mind, however, that the atmosphere of a planet does not necessarily reflect the most prevalent metabolic pathway on that planet. Thus, on Earth, the most prevalent gas is nitrogen whereas the most metabolically important gases are oxygen and carbon dioxide.

While mere detection of a trace gas would be biologically significant, evidence of surface metabolic activity could be obtained if the IRIS detects variations in gas concentrations or in isotopic ratios with time and location. Metabolic activity could also be implied from vertical concentration gradients of gases or from certain anomalies in the concentrations of a particular gas. The latter approach offers considerable promise.

In addition to gases, many organic compounds, if detected in the Martian atmosphere, would be indicative of life processes. Terpenes, for example, are common end products of terrestrial plant metabolism and are prevalent in the Earth's atmosphere. These and other hydrocarbons are oxidized by ozone and may, if fact, be responsible for the "blue haze" seen in the Earth's atmosphere over foliage areas. Other hydrocarbons present in the Martian atmosphere could also be indicative of types of compounds available to Martian organisms for metabolism.

In view of the possibilities of atmospheric analysis for making biological inferences, it is recommended that future efforts be focused

in this direction. Imperative for analyzing atmospheric data to be obtained by IRIS will be the prior establishment of signatures and detection limits of all anticipated atmospheric constituents. These include a variety of gases, terpenes, and other organic compounds. In addition, further efforts should be made to obtain information about other gases or organic compounds which could play a role in Martian metabolism and consequently may be present in the Martian atmosphere. Finally, to interpret the IRIS data showing the trace constituents, it will be necessary to acquire a thorough knowledge of atmospheric photochemistry. This knowledge may point out some anomaly in the presence or absence of a particular gas which will provide insight into Martian metabolic processes.

Respectfully submitted,

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