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The Viking Biological Experiments on Mars[1]

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The essential findings of the three biological experiments aboard the two Viking Mars landers are reviewed and compared. All three of the experiments yielded significant data in repeated tests of Martian surface samples. Some of the results are consistent with a biological interpretation, although there are serious reservations in accepting this conclusion. Most of the findings, however, are inconsistent with a biological basis. The combined data suggest the presence of several classes of oxidants on Mars and these would account for most of the observations. An explanation for the apparent small synthesis of organic matter in the pyrolytic release experiment remains obscure.

INTRODUCTION

The Viking biological experiments have been described in previous publications (Klein *et al.*, 1972; Klein, 1974; Klein *et al.*, 1976a) and most of the experimental data obtained on Mars for each experiment have now been presented by the respective principal investigators (Klein *et al.*, 1976b; Horowitz, Hobby and Hubbard, 1976 and 1977; Oyama *et al.*, 1977; Oyama and Berdahl, 1977; Levin and Straat, 1976a, 1977a,b; Klein, 1977). Notwithstanding the availability of these important contributions, it may be useful to recapitulate the major findings in each experiment, to compare the different experiments to see whether and how the results may complement or negate each other, and to examine and analyze the various conclusions that may be drawn from the results that were obtained.

[1] This paper is based on a presentation made at the "Viking Science Symposium" of the COSPAR meeting held in Tel-Aviv, Israel on June 10, 1977.

METHODS

Descriptions of the three biology instruments are available (Brown *et al.*, 1978), as are details concerning the ground-based tests out of which were developed the empirical criteria which were to be used in assigning "positive" or "negative" de-descriptions to the Martian samples (Hubbard, 1976; Levin and Straat, 1976b; Oyama *et al.*, 1976). An analysis of some of the more important constraints under which the Martian experiments were conducted has also been made (Klein, 1976, 1977).

DISCUSSION OF RESULTS

The Gas Exchange (GEx) Experiment

This experiment, which periodically measured the composition and quantity of gases over samples of Martian surface material, was performed in two modes. Initially, after acquisition of the samples, nutrient medium was added in such a way that the "soil" did not come into contact

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TABLE I

GAS EXCHANGE EXPERIMENT (HUMID MODE)

POSSIBLE INTERPRETATIONS

INTERPRETATIONS	CONTRAINDICATIONS
• REACTION IS BIOLOGICAL	• REACTION IS EXTREMELY RAPID
	• REACTION OCCURS ONLY INITIALLY
	• NO REASONABLE BIOLOGICAL MECHANISM
	• REACTION IS STABLE TO PRIOR HEATING AT 145°C
• REACTION IS NON-BIOLOGICAL	
• H_2O_2 IS SOURCE OF OXYGEN	• REACTION IS STABLE TO PRIOR HEATING AT 145°C
	• REACTION IS STABLE TO STORAGE OF "SOIL" FOR MONTHS AT ~15°C
• METALLOPEROXIDE(S) OR SUPEROXIDE(S) SOURCE OF OXYGEN	

with the nutrient, but was nevertheless exposed to water vapor in the atmosphere (Klein *et al.*, 1976a). In this mode, the so-called "humid mode," the only significant data obtained indicated that some CO_2 and N_2 were desorbed from the soil at this time and there was a surprising and rapid accumulation of oxygen after humidification (Oyama and Berdahl, 1977) each of the three times that the experiment was carried out.

The release of oxygen upon humidification had never been observed before in tests with terrestrial or lunar surface samples (Oyama *et al.*, 1976). The process leading to the accumulation of oxygen is poorly understood. In Table I are given the major arguments for considering this process to be of nonbiological origin. The arguments against a biological interpretation are, first, that the reaction was extremely rapid—by $2\frac{1}{2}$ hr after adding water to the incubation chamber, most of the oxygen had already been released; the reaction was essentially over by the time the subsequent analyses were made (beginning a day or two after the initial analyses). Second, later addition of water directly to the soil caused no further liberation of oxygen. Third, in the absence of any added source of energy (these experiments were conducted in the dark), no plausible biological mechanisms are apparent. Finally, in one of the last experiments performed on Mars, we found that oxygen was also released from a sample that had been heated to "sterilizing" temperatures (145°C).

If the reaction is not biological, what then is the source of oxygen? It is not likely to be hydrogen peroxide, which may well be present in these Martian samples (see below). This is because H_2O_2 should not have survived in those samples that released oxygen after heating to 145°C for 3 hr and then being exposed to the Martian atmosphere. Nor is it likely that H_2O_2 would persist in other samples that had been exposed to spacecraft temperatures for several months in equilibrium with the Martian atmosphere.

The notion that metaloperoxides or superoxides may be present on Mars and enter into reaction with water has been proposed by Oyama *et al.* (1977) and seems to be reasonable. Such a model would also help explain the absence of any significant amounts of organic matter in the Martian samples (Biemann *et al.*, 1977).

In its second mode of analysis, (i.e., with nutrient *in contact* with the samples), the gas exchange experiment yielded a number of significant findings (Oyama and Berdahl, 1977) which are summarized in Table II.

Soon after the nutrient solution contacted the samples, about 30% of the gaseous CO_2 went into solution. Also noted at this time, was an uptake of the oxygen that previously had been liberated in the humid mode. With continued incubation

TABLE II

GAS EXCHANGE EXPERIMENT (WET, NUTRIENT MODE)

SIGNIFICANT DATA

- UPTAKE OF CO_2 UPON INITIAL WETTING OF "SOIL".
- UPTAKE OF O_2 UPON WETTING "SOIL".
- SLOW, PROLONGED, RELEASE OF CO_2.
- NO OTHER GAS CHANGES (FOR UP TO 7 MONTHS).

of these samples, CO_2 was slowly and continually produced so that eventually the total CO_2 returned to the original levels and thereafter continued to increase with time. Once again, no other gas changes were noted, even in experiments that involved incubation periods of several months.

It is extremely unlikely that any of these gas changes are of biological origin (Table III). First, the absorption of CO_2 in this manner was observed also in samples that had been "sterilized" at 145°C. Second, the amounts of oxygen taken up are readily accounted for by the ascorbic acid which was present in the nutrient solution (Oyama and Berdahl, 1977). Last, with regard to the slow continued production of CO_2, when the nutrient solution was drained out of the incubation chambers and fresh nutrient added back to the incubating samples, the rate of production of CO_2 always slowed down and became more sluggish with each fresh charge of nutrient. Such reactions had often been seen in sterile terrestrial samples and indicate a dissipative chemical reaction (Oyama *et al.*, 1976).

The most reasonable interpretation for the uptake of CO_2 is that it is nonbiological and that metal oxides or hydroxides, *created by* the initial interaction of water with peroxides or superoxides, result in strongly basic solutions. Thus with each addition of nutrient (water), the further dissolution of CO_2 in the aqueous phase is favored.

The nature of the process that leads to the slow, prolonged release of CO_2 is not at all certain. It is possible, as Oyama has shown in ground-based experiments with γ-Fe_2O_3 (Oyama *et al.*, 1977), that some of the nutrient was slowly oxidized on Mars by some *secondary* oxidant, like iron oxide, in the samples.

The Labeled Release (LR) Experiment

In the LR experiment (Table IV), there were a number of significant observations (Levin and Straat, 1976a, 1977a,b). Foremost was the consistent finding that addition of an aqueous solution solution of dilute radioactive organic compounds to Martian samples resulted in a rapid release of labeled gas. This process was virtually eliminated by prior heating of the samples at about 160°C for 3 hr, and was substantially reduced by heating to only 45 to 50°C. As in the case of the gas exchange experiment, upon prolonged incubation, there was a slow continued evolution of labeled gas after the initial reactions were

TABLE III

GAS EXCHANGE EXPERIMENT (WET, NUTRIENT MODE)

POSSIBLE INTERPRETATIONS

INTERPRETATIONS	CONTRAINDICATIONS
• REACTIONS ARE BIOLOGICAL	• CO_2 UPTAKE ALSO IN "SOIL" HEATED TO 145°C
	• O_2 UPTAKE EQUIVALENT TO ASCORBIC ACID IN NUTRIENT
	• CO_2 SLOW RELEASE IS DISSIPATIVE
• REACTIONS ARE NON-BIOLOGICAL	
• METALLIC OXIDES OR HYDROXIDES ABSORB CO_2 WHEN WET	
• METALLIC OXIDES SLOWLY OXIDIZE ADDED ORGANICS	

TABLE IV

LABELED RELEASE EXPERIMENT

SIGNIFICANT DATA

- RAPID DECOMPOSITION OF PORTION OF ADDED NUTRIENTS.
- COMPLETE INHIBITION OF REACTION BY PRIOR HEATING AT 160°C/3 HRS.
- SUBSTANTIAL REDUCTION OF REACTION BY PRIOR HEATING AT 45-50°C/3 HRS.
- SLOW, PROLONGED RELEASE OF LABELED GAS AFTER INITIAL FAST REACTION.
- UPTAKE OF LABELED GAS UPON ADDITIONAL WETTINGS.
- COMPLETE LOSS OF REACTION IN "SOILS" STORED AT SPACECRAFT TEMPERATURES FOR OVER 4 MONTHS.

over. Also, each time additional liquid was added, again about 30% of the labeled gas in the test cell went into solution. *Finally, in contrast to the results obtained in the gas exchange experiment,* storage of the samples for 2 to 4 months, essentially eliminated the agent(s) responsible for the rapid decomposition of the nutrient in the LR experiment.

In many respects, the LR data are entirely consistent with a biological interpretation (Levin and Straat, 1976b). Indeed, if information from other experiments on board the two Viking landers had not been available, this set of data would almost certainly have been interpreted as presumptive evidence for biology.

As seen in Table V, however, there are some important problems with assigning a biological explanation to these findings. First, the initial reaction is so rapid, so intense, that this would seem to suggest a large biological "load" in the samples—at least by analogy with terrestrial samples. Since the sensitivity of the Viking organic analysis experiment was such that the organic content of approximately 10^6 cells of *Escherichia coli* could have been detected —but was not—it is useful, although obviously not conclusive, to compare the rates of gas evolution seen in the LR experiment on Mars to actively metabolizing terrestrial systems in order to attempt to estimate the biological "load" in the LR samples. The initial rates of gas evolution (assuming the gas to be CO_2) were approxi-

TABLE V

LABELED RELEASE EXPERIMENT

POSSIBLE INTERPRETATIONS

INTERPRETATIONS	CONTRAINDICATIONS
• REACTIONS ARE BIOLOGICAL	• EXTREMELY VIGOROUS INITIAL REACTION, NOT CONSISTENT WITH GCMS DATA
	• REACTION SLOWS DOWN WITH OVER 90% OF SUBSTRATES STILL AVAILABLE
	• NO MECHANISM FOR UPTAKE OF GAS UPON SUBSEQUENT WETTING
	• EVIDENCE FOR OXIDANT(S) IN "SOIL"
• REACTIONS ARE NON-BIOLOGICAL	• NO CORRELATION BETWEEN AMOUNT OF O_2 RELEASED (IN GEx) AND LR RESPONSE IN FRESH "SOILS"
• "SUPEROXIDES" OXIDIZE ORGANICS	• "SUPEROXIDES" STABLE TO HEATING AT 145°C; LR RESPONSE IS NOT
	• LR RESPONSE LOST ON STORAGE; GEx RESPONSE IS NOT

TABLE VI

COMPARISON BETWEEN CO_2 EVOLUTION BY FERMENTING YEAST AND LR EXPERIMENTS

	YEAST (mg, WET WT.)	LR RESPONSE
CO_2 PRODUCED PER HR.	~ 30 μl[1]	$\geq$ 0.1 μl
EQUIVALENT NUMBER CELLS	7.7×10^6[2]	2×10^4
EQUIVALENT E. COLI CELLS	1.25×10^9[2]	3.2×10^6

[1]HENNEBERG, W., HANDB. DER GÄRUNGSBAKTERIOLOGIE (1926)
[2]RAHN, O., "PHYSIOLOGY OF BACTERIA" (1932)

mately 0.1 μl or more per hour in the labeled release experiment. By comparison, vigorously fermenting yeast cells produce CO_2 at a rate of about 30 μl/hr/mg, under optimal conditions (Hennenberg, 1926). Since the number of *E. coli* cells equivalent to 1 mg of yeast is about 1×10^9 (Rahn, 1932), the LR response would correspond to at least 3.2×10^6 *E. coli* cells (Table VI). Such an initial "inoculum" of living cells—quite apart from any associated dead cells or cell debris—is inconsistent with the organic analysis data. (Recognizing that all of the biological experiments (on Mars) were performed at temperatures considerably higher than the prevailing mean or even prevailing high temperatures at the Martian sites, one might, in fact, expect metabolic reactions to have been impaired, and thus the true "biological" load in these samples should even be higher than this.)

Furthermore, the vigorous reaction seen in the labeled release experiment essentially ceases with over 90% of the available organic substrates still unattacked, which conceivably could be due to a highly selective catabolic system in Martian organisms capable of specifically destroying only one of the organic compounds (formate ?) in the nutrients. This observation may also be the result of the depletion of one of the reactants involved in the simple oxidation of the organic compounds in the nutrient solution by an inorganic soil oxidant. A biological interpretation also provides no basis to explain the *uptake* of labeled gas upon subsequent wetting of the sample. And, finally, one cannot ignore the evidence suggesting the presence of oxidizing compounds on Mars as observed directly in the GEx experiments, and indirectly in the organic analysis experiments.

If the labeled release data are not produced by biological processes, are superoxides of the type indicated in the GEx experiment data responsible for the rapid decomposition seen in these experiments? This is not likely for several reasons. First, there is no direct correlation between the capacity of a sample to yield O_2 upon becoming wet and the ability of the same material to decompose the labeled release nutrients (Table VII). Another argument against the involvement of a common oxidant in these two experiments is that the LR reaction is much more sensitive to prior heating than is the O_2-generating reaction (Table VIII). Finally, storage of Martian samples resulted in loss of activity in the LR experiment, but storage did not eliminate the O_2-generating reaction in the gas exchange experiment (Table IX). Thus, if an oxidant is involved in the rapid

TABLE VII

COMPARISON OF DATA FROM LR AND GEx EXPERIMENTS

SAMPLE	OXYGEN RELEASED (GEx)*	CARBON DIOXIDE PRODUCED (LR)*
VIKING 1 – (SURFACE)	770	~30
VIKING 2 – (SURFACE)	194	~30
VIKING 2 – (SUB-ROCK)	70	~30

*NANOMOLES PER 1 CC SAMPLE.

TABLE VIII

EFFECT OF PRIOR HEATING ON GAS EXCHANGE AND LABELED RELEASE EXPERIMENTS

TEMPERATURE C°	GAS EXCHANGE (O_2 GENERATION) %	LABELED RELEASE (CO_2 GENERATION) %
10-15	100	100
45-50	–	30
145-160	$\geq$50	0

TABLE IX

EFFECT OF STORAGE ON BIOLOGY EXPERIMENTS

STORAGE[1] (DAYS)	PR[2] EXPERIMENT	GE[3] EXPERIMENT	LR[4] EXPERIMENT
NONE[5]	ACTIVE	ACTIVE	ACTIVE
3	–	–	ACTIVE
33	–	ACTIVE	–
71	ACTIVE	–	–
82	–	–	INACTIVE
143	ACTIVE	ACTIVE	INACTIVE

1. AT SPACECRAFT TEMPERATURES (6-20°C).
2. ACTIVE = SIGNIFICANT SECOND PEAK.
3. ACTIVE = O_2 GENERATION WHEN SOIL WAS WETTED.
4. ACTIVE = RAPID RELEASE OF RADIOACTIVE GAS.
5. FRESH SAMPLES WERE INITIATED WITHIN 2 DAYS OF ACQUISITION.

TABLE X

LABELED RELEASE EXPERIMENT

– POSSIBLE INTERPRETATIONS CONTINUED –

INTERPRETATIONS	CONTRAINDICATIONS
• REACTIONS ARE NON-BIOLOGICAL • CO IS RELEASED FROM HCOOH	• REQUIRES NEUTRAL OR ACID pH FOR "SOILS" • INCONSISTENT WITH MEASURING CHANGES IN CO_2 IN GEx • NO RATIONALE FOR EFFECTS OF STORAGE ON REACTION • DOES NOT ACCOUNT FOR SLOW RESIDUAL REACTION
• REACTIONS ARE NON-BIOLOGICAL • H_2O_2 RESPONSIBLE FOR INITIAL REACTION • OTHER OXIDANT RESPONSIBLE FOR SLOW RESIDUAL REACTION	

labeled release reaction, it must be different than the one involved in the O_2-generating reaction.

Other possible interpretations are shown in Table X. A rather novel interpretation has been made by Plumb (1977) who recently suggested that the labeled gas that was released on Mars in this experiment is not CO_2, that is, that no oxidation of nutrients is involved at all, but rather a loss of CO from the formate present in the nutrient solution due to a change in the pH of the nutrient upon contact with the Martian soil.

The arguments against this view are first, that this requires a neutral or acid pH for the Martian samples, and the available evidence suggests an alkaline one (Oyama *et al.*, 1977). Second, under essentially similar conditions, in the gas exchange experiment, when organic nutrients came into contact with the Martian samples, the release of CO_2 was actually measured. The proposed idea also does not account for the loss of activity upon prolonged storage of the samples.

That H_2O_2 itself may be the major oxidative reactant in the labeled release experiment has also been suggested by numerous investigators (Ponnamperuma *et al.*, 1977), since its properties would appear to be consistent with the available data.

In considering all of the data from the labeled release experiment, it appears necessary to postulate yet a *third* oxidant in the Martian soil. This agent would be in addition to the "superoxides" presumably causing the generation of oxygen, and the H_2O_2 presumably decomposing the labeled release nutrient. This third oxidant would then account for the slow release of labeled gas *after* the initial reactions of the LR and GEx experiments are over. This oxidant does not appear to be heat sensitive and is not destroyed by storage—thus distinguishing it from H_2O_2. It also persists long after the so-called "superoxides" have reacted with H_2O—thus distinghishing it from this category of oxidants.

The Pyrolytic Release (PR) Experiment

In this experiment, the significant findings are listed in Table XI. Weak, but significant "positives" (Hubbard, 1976) were obtained at both sites (Horowitz *et al.*, 1976, 1977). Prior heating of a sample at 175°C for 3 hr drastically cut down—but did not completely eliminate—the reaction, while heating at 90°C had no deleterious effect. The data suggest that the reaction goes better in the light but this conclusion requires comparing "light" reactions on one lander with "dark" reactions on the other. Finally, storage did not reduce the capacity of the Martian samples to yield statistically positive results (Table IX).

TABLE XI

PYROLYTIC RELEASE EXPERIMENT

SIGNIFICANT DATA

- WEAK, BUT STATISTICALLY SIGNIFICANT "POSITIVES".
- "STERILIZATION" AT 175°C/3 HR. STRONGLY REDUCES REACTION.
- HEATING AT 90°C/2 HR. DOES NOT REDUCE REACTION.
- REACTION PROCEEDS SOMEWHAT BETTER IN LIGHT.
- STORAGE OF "SOIL" WITHIN SPACECRAFT FOR 4 MONTHS DOES NOT AFFECT REACTION.

Are these reactions biological? Probably not (Table XII). First of all, heating the samples to 90°C has no inhibitory effect on the reaction, and 175°C heating does not completely abolish it. Then, the presence of H_2O, which would perhaps be expected to enhance the biological reduction of CO or CO_2 to organics, appears to be inhibitory —and at low concentrations on the order of that which should, at times, be present on Mars. Finally, the organic analysis results also bear on this experiment. Since the GCMS could not detect indigeneous organics in any of the samples tested, at levels down to parts per billion (Biemann, 1977), organics clearly do not accumulate in significant amounts on Mars. While scenarios can be imagined which allow for an extremely low, steady-state concentration of organics, the turnover of such minute amounts of carbon would suggest a very sparse biota at best, and it is not easy to see how such a biological system could be sustained over long periods of time.

If the PR results are *nonbiological*, are

TABLE XII

PYROLYTIC RELEASE EXPERIMENT

POSSIBLE INTERPRETATIONS

INTERPRETATIONS	CONTRAINDICATIONS
• REACTION IS BIOLOGICAL	• INSENSITIVITY TO 90°C HEATING
	• INHIBITION BY H_2O (VL2)
	• ABSENCE OF ORGANICS IN GCMS
	• HEATING AT 175°C DOES NOT COMPLETELY ABOLISH REACTION
• REACTION IS NON-BIOLOGICAL	
• MARTIAN OXIDANT(S) REACT WITH CO TO FORM ORGANICS	• SUPEROXIDES, METALLOPEROXIDES, H_2O_2 SHOULD HAVE BEEN ELIMINATED IN CHRYSE 5 EXPERIMENT
	• REACTION PROCEEDS WITH "SOIL" STORED FOR 70 DAYS
• ORGANICS FORMED FROM CO BY "SOIL" CATALYSTS	• CATALYST(S) STABLE AT 90°C BUT NOT AT 175°C

TABLE XIII

PYROLYTIC RELEASE EXPERIMENT

POSSIBLE INTERPRETATIONS (CONTINUED)

INTERPRETATIONS	CONTRAINDICATIONS
• REACTION IS NON-BIOLOGICAL	
• NO ORGANICS FORMED; ARTEFACT CAUSED BY C_3O_2 POLYMER	• DOES NOT ACCOUNT FOR ENHANCEMENT OF REACTION BY LIGHT
	• REQUIRES POLYMER TO BE STABLE AT 90°C BUT NOT AT 175°C
• NO ORGANICS FORMED; ARTEFACT CAUSED BY ADSORBED CO_2	• REQUIRES CONSISTENT INSTRUMENT ANOMALY
	• DOES NOT ACCOUNT FOR EFFECT OF "STERILIZATION"
• NO ORGANICS FORMED; INSTRUMENT ARTEFACT AFFECTING "ORGANIC VAPOR TRAPS"	• NO EVIDENCE FOR VARIATIONS IN FLIGHT-TYPE OVT'S
	• PRE-FLIGHT TEST PROGRAM INDICATED EFFECT OF VACUUM WAS CORRECTABLE

they directly related to the superoxides or H_2O_2, postulated to explain the major data in the other experiments? This does not seem to be the case because of one experiment that was conducted at the Chryse 5 site on Viking I. In this experiment, the sample was first humidified for several hours, after which the test cell was heated and vented to dry out the sample. This treatment should have removed, or at the very least greatly decreased, both of the major postulated oxidants ("superoxides" and H_2O_2). However, after this treatment, the Martian sample still yielded a "positive." Another experiment which distinguishes the results of the pyrolytic release experiment from those of the labeled release experiment occurred when samples were stored prior to analysis (Table IX). This treatment which presumably eliminated the oxidant responsible for the LR results had no effect on the pyrolytic release reaction.

One possible nonbiological mechanism to account for the formation of organics is suggested in the early work of Hubbard and co-workers (1971) who studied the surface catalysis of the reduction of CO to organics. While terrestrial soils have not shown such effects except in the presence of uv light (which was filtered out in the Viking experiments (Hubbard, 1976)), it is possible that Mars has catalysts which allow this reaction to proceed in the absence of uv light and even in the dark. If so, however, the Martian catalysts must be stable to heating at 90°C, but not at 175°C.

There are other possible interpretations of the puzzling results obtained in this experiment, three of which are shown in Table XIII. All of these have in common the suggestion that *no organics were formed* during the Viking experiments. One explanation, proposed by Oyama *et al.* (1977), is that some of the labeled carbon used in the incubation gas mixture is incorporated during incubation into preformed carbon suboxide polymer (C_3O_2), (presumed to exist on Mars), and that the remaining steps in the operational sequence of the experiment yield an artifactual, or false, positive. This idea does not account for any enhancement of the reaction by light (albeit the evidence for this is not very strong). Also, it would require the polymer to be stable at 90°C but not at 175°C.

A somewhat related suggestion has been made by Hugenin (1976), who suggested that during incubation labeled gas molecules will simply become adsorbed to activated surface grains to form carbonate complexes which, upon subsequent processing in the experiment, yield an artifactual positive. In this case, the scheme requires a rather consistent instrument anomaly, which is unlikely. In addition, the scheme does not account for the apparent effects of sterilization.

During the mission, the Viking Biology team also considered another explanation: the very crucial organic vapor traps (OVT's), which allow separation of organic fragments from CO_2 and CO may have developed some anomalous properties—having been exposed to space vacuum for about a year during the trip to Mars. It is possible, according to this view, that the effects seen in the PR experiment are simply due to inadequately prepared OVT's. However, this would require that the OVT for VL 1 have somewhat different properties than the OVT for VL 2, and we have seen no such variability from several other OVT's manufactured at the same time. Also, on the basis of preflight tests (where the effects of vacuum were considered) corrective measures were inserted into the experiment sequence to eliminate this problem.

Finally, it should be emphasized that, while the weight of the evidence argues against a biological interpretation for the PR experiment results, the nonbiological explanations that have been proposed all have little or no experimental validation at this time, and it is clearly a possibility that new, and perhaps more plausible, ideas will emerge in this area.

SUMMARY

To summarize the current status of our interpretations, *all* the data taken together would seem to point toward nonbiological explanations for *all* of the observed reactions in the Viking experiments. The presence on Mars of three different oxidants: "superoxides," H_2O_2, and iron oxide (possibly γ-Fe_2O_3), would explain most of the gas exchange and labeled release data but at present the explanation of the PR results remains very murky.

Having briefly reviewed these matters here, it should not come as a surprise that a number of laboratories have initiated ground-based studies to help elucidate the Viking biology experiment findings. A summary account of the status of these investigations is being prepared.

In conclusion, in assessing the probabilities of life on Mars, we must not overlook the fact that all of the Viking biological experiments were carried out under conditions that deviated to varying extents from ambient Martian conditions. Therefore, while we have obtained significant and fascinating data in the Martian experiments, we may not have hit upon the the proper conditions to elicit evidence of Martian metabolism (Klein, 1977), and in trying to uncover the mechanisms behind these observations we *may* be seeking mechanisms for reactions that are coinci-

dental to the central issue of whether or not there is life on Mars.

Nevertheless, taking into account all of our data, the photographic data, and the data from the organic analysis experiments, it is fair to say that if life exists on Mars, it must be constrained within narrow geographical or metabolic limits. The Viking experiments were predicated on a model for Mars that assumed widespread distribution of Martian biota and on the assumption that the specific range of environments provided by the biological experiments (Klein, 1977) would be adequate to elicit evidence of metabolism by Martian organisms. These assumptions may not, in fact, apply to the situation on Mars.

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