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A REAPPRAISAL OF LIFE ON MARS

[NMC-1J]

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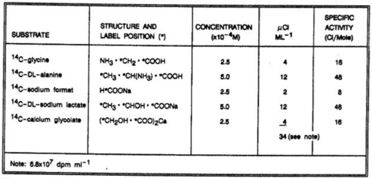
A decade has passed since the first labeled-release (LR) Viking biology experiment produced an astonishing positive response on Mars. But that response was deemed unconvincing when no organic compounds was found. As a result, many attempts have been made to explain the LR data without invoking life. The dominant theory expounded hydrogen peroxide as a chemical agent, suggesting that it reacted with one of the nutrient compounds to mimic a biological response. This theory was tested and essentially disproved on Mars. There is in fact no evidence that it exists on Mars, and even if it formed it would be destroyed by the environment long before it could affect an experiment. We have carefully tested all of the nonbiology theories and have found none to be scientifically adequate. We also verified that the GCMS organic detection sensitivity may have missed very low densities of organic matter. It is now our contention that the survival of the LR data, together with other information not previously considered (including Viking lander image and spectral data that suggest the possible existence of martian lichen), justifies the conclusion that it is now more probable than not that the LR experiment did in fact detect life on Mars.

OPENING COMMENTS AND REVIEW

It is great to get back to the subject of life on Mars. I took issue with the title originally pro- posed for my presentation(1)--A Second Opinion--because I think all the opinion and philosophy one needs on this topic has already been delivered and it is our intent to stick strictly to the facts in presenting our own conclusions.

It has been a decade now since martian soil was wetted with labeled nutrient (radio-carbon. ^{14}C) in the Viking labeled-release (LR) experiment. yielding the astonishing result of a rapid and continuing evolution of radioactive gas over a period of eight days. Figure 1J-1 is a table of the nutrients used in the LR experiment [Levin and Straat(2), 1976]. When the positive signal came back from Mars, we immediately applied the control procedure we thought we would never have to use --we heated a control portion of the same sample to 160°C (320°F). It produced no response. Therefore, the preflight criteria published for the experiment (blessed and approved by NASA. the National Academy of Sciences. the Space Sciences Board, et-cetera) were fully demonstrated.



SUBSTRATE	STRUCTURE AND LABEL POSITION (*)	CONCENTRATION ($\times 10^{-4}$M)	µCI ML^{-1}	SPECIFIC ACTIVITY (CI/Mole)
^{14}C-glycine	$NH_3 \cdot {}^*CH_2 \cdot {}^*COOH$	2.5	4	16
^{14}C-DL-alanine	${}^*CH_3 \cdot {}^*CH(NH_3) \cdot {}^*COOH$	5.0	12	48
^{14}C-sodium format	$H{}^*COONa$	2.5	2	8
^{14}C-DL-sodium lactate	${}^*CH_3 \cdot {}^*CHOH \cdot {}^*COONa$	5.0	12	48
^{14}C-calcium glycolate	$({}^*CH_2OH \cdot {}^*COO)_2Ca$	2.5	4	16
			34 (see note)	

Note: 6.8×10^7 dpm ml^{-1}

Figure 1J-1: Table of Nutrients Used in Viking LR Experiment

Level of Confidence Prior To and During Mission

In spite of the initial positive results, however, our Viking LR data were deemed unconvincing because of the lack of supporting data from other experiments on the landers, notably the search for organic matter. This reflected a change in scientific disposition, in that during preparations for the mission we had been told by NASA that it had selected the three experiments for the Viking biology package(3) such that each would test a different model for potential martian life. It was understood at that stage, then, that only one of the three experiments might return a positive response, were there truly life on Mars, and that such independent data would most probably be strong enough on its own merit to substantiate the detection of life.

Failure* to *Find Organic Matter --The molecular analysis experiment, utilizing a gas-chromatograph/mass-spectrometer (GCMS) specifically designed for the Viking mission, failed to find organic compounds in the martian soil. This indeed created a problem for our results, because it is difficult to suggest that life has been detected where no organic matter can be found. With no organic chemistry detected to support the positive conclusions suggested by the LR responses, many attempts were immediately made to explain the results without invoking life.

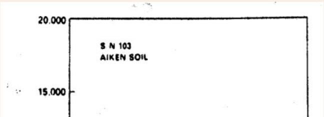
However, none of these explanations has been adequate to the task over the ten-year period since our data were acquired. Indeed, it is our contention that the survival of the LR data in the face of these attempts to discredit them, together with possible visual (photographic) evidence of martian life produced by the lander cameras (and other data heretofore not considered with respect to this question), now justifies the conclusion that it is more probable than not that the LR experiment did in fact detect life on Mars.

Instrument Performance Integrity --The Viking LR experiment represented a fifteen-year test and development program(4). It was extraordinarily sensitive and could detect as few as several cells per cc of soil. In hundreds of laboratory and field tests, it never once provided a false positive response.

The test program was concluded with a full-up experiment in a proof-test instrument identical to the one flown to Mars; with the exception that, because we had no martian soil, we instead used some California soil provided by NASA. Prior to the experiment, the soil was exposed for three days to a simulated environment modeled on the best-available experience for what was anticipated on Mars.

Labeled-Release Results on Mars

In Figure 1J-2, representing results of the pre- Viking tests using the California soil, a response is seen to rise quickly to about 10,000 counts per minute (cpm) during the eight-day period of a single experiment cycle, which represents the standard cycle period pre-programmed into the LR Instrument. Elevating the temperature of a duplicate (control) sample to 160°C for three hours prior to testing it produced essentially a negative response. The test results illustrated were produced under simulated Mars environmental conditions with a moderately populated terrestrial soil. However, results were equally dramatic following the actual landing on Mars.



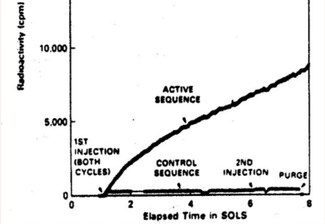


Figure 1J-2: Responses From California Soil; Natural (active) and Sterilized (control), Performed In Simulated Mars Environment

VL-1 LR Results --Four cycles of Viking experiments conducted by the first lander (VL-1) on Mars(5) are illustrated in Figure 1J-3: two actives and two controls. The active cycles reflect the same kind of response seen in the terrestrial experiment previously illustrated (Fig. 1J-2), with measurements in the 10,000 to 15,000 cpm range. The on-Mars control cycles produced responses essentially at the background level for the instrument, although background levels on the Mars landers were somewhat higher due to radiation from the two nearby nuclear power generators(6).

VL-2 LR Results and the UV Theory --At the second landing site(7), the same sort of result evolved as we processed the first VL-2 sample. Initial VL-2 results are illustrated in Figure 1J-4. One of the nonbiological explanations almost immediately theorized by some was that ultra-violet (UV) light striking the surface of Mars somehow "activated" the soil to produce the positive response. At the VL-2 site, however, we were able to get additional data to test that particular theory by manipulating the experiment from Earth. The lander control engineers cleverly extended the soil sampler before dawn one morning (to avoid UV radiation exposure for a sample being retrieved), moved a small rock that had provided UV shielding for the small area of soil beneath it for perhaps a few hundred thousand or even millions of years, and acquired a sample of that protected soil for analysis. Only slightly weaker, that sample also responded in the active area at about 8,000 or 9,000 cpm.

Adapting the Experiment* to *Mars --Based on Viking experience, we then further modified the pre-mission experiment criteria such that our on-Mars results would be more acceptable to the scientific community. Initially, for example, if we had gotten a zero response after heating a duplicate soil sample (as a control for one that had produced a positive response) to 160°C, the result would have been construed as evidence that the positive response had in fact evolved from living organisms that could be destroyed by the high temperature used during the control procedure.

To improve the basis of that control for Mars, we wanted to adjust the test criterion to a more conclusive temperature. We ultimately succeeded in reducing it to Just 50°C (122°F), a relatively severe (warm)--though not necessarily or immediately destructive--temperature on Mars(8). Our chemistry-oriented colleagues agreed that this temperature would likely be able to damage Mars organisms without inhibiting the chemical reactions they believed were mimicking life and producing our results. If our data were in fact due to a chemical reaction, the response should not have been reduced at that temperature. Instead, as seen in Figure 1J-4. the result was a response reduction of about 65%, which is more in keeping with what one might expect had a quantity of living organisms been attenuated at that modest temperature. Clearly, then, this experiment provided further support for a biology rationale.

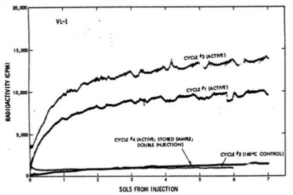


Figure 1J-3: Results From LR Experiment Cycles for VL-1

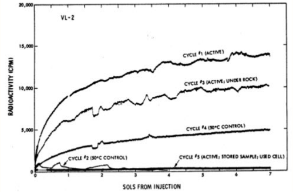


Figure 1J-4: Results From Experiment Cycle for VL-2

Effects of Long- Term Sample Storage --Another analysis opportunity, however, afforded through what might be called "inadvertence" or serendipity, proved to be even more important. We were able to test a sample that had been held in the sample collection hopper for two to three months. A portion of the sample had been tested at the time of its acquisition and had produced a positive response. Aside from the fact that it was then retained in a dark box (inside the lander a couple of feet above the surface of Mars) and maintained there at a temperature of about 10°C, nothing had happened to that sample.

The negative results of this analysis are reflected as Cycle 5 (Fig. 1J-4). At ambient temperature, the disappearance of an indigenous chemical merely placed in a dark box is hard to explain. Because of the nature of this particular sample and the results of its analysis, one is led to conclude that something mysterious was indeed going on, e.g., the evaporation of hydrogen peroxide (after causing the LR response). In the case of hydrogen peroxide, however, it would have been necessary for it to reform every day in amounts large enough to produce the response. The alternative, of course, is that something had died.

MARS AND EARTH EXPERIMENT SAMPLES IN COMPARISON

Had the strong positive response we got on Mars been produced by Earth samples, as indeed similar results often were, the data would have served as unquestionable proof for the presence of organisms in the soil. At the very least, the scientific community should grant that the Viking LR data are evidence for life on Mars. It has been stated by others that "there is no evidence" for life on Mars. Evidence is defined as being distinct from proof, in that evidence is something to be considered when trying to determine whether proof exists. While I have never claimed the latter, I DO submit that our experiment produced scientifically sound evidence for martian life, and that it is for the future to determine whether it is or is not associated with proof of martian life.

Differing Earth and Mars Results

The LR results were not without some disappointments. When a second dose of nutrient was applied to martian samples (following the completion of cycles during which positive responses were detected), we anticipated--as was usually seen in terrestrial samples--a renewal of gas evolution as a result of new growth. However, there was no increase when the second injections were made on Mars after the eighth sol(9), as Cycle 1 at the VL-1 site demonstrates in Figure 1 J-5. Indeed, a decrease in the amount of gas in the atmosphere of the test cell is clearly defined. The lack of gas production following the second injection of nutrient led some to conclude that no life was present in the soil.

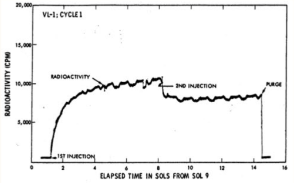


Figure 1J- 5: Results of Cycle 1 (1st and 2nd Injections, VL-1)

Terrestrial Analogue --We more recently reviewed our library of results with terrestrial samples in search of data reflecting a response behavior similar to our Mars results, and found Antarctic test soil No. 664(10). In that soil (pH = 8.1), which initially produced a positive response with the first injection, we found that some of the gas had been readsorbed following the second injection and that the analysis essentially mimicked the Mars result. The pertinent data from this experiment are reflected in Figure 1J-6. In this soil, then, which had been shown to contain microorganisms [Cameron et al. 1970[a]] in classical microbiological tests, we demonstrated the death of those organisms after eight days (in Viking LR test instrument at 23. C). Could this not have happened on Mars?

The Hydrogen Peroxide Issue

Factors Involved In Formate-Peroxide Theory --After the initial positive results were known, the theory expounding hydrogen peroxide (H_2O_2) was almost immediately proposed as a non- biological explanation. It suggests that hydrogen peroxide continually forms in the martian atmosphere and precipitates to the surface, where--when taken into an experiment like our LR Instrument--it can react with one of the labeled nutrient compounds, ^{14}C-sodium formate. Indeed, the theory held that formate was the only labeled compound in the LR nutrient that would react with peroxide. Each of the seven substrates (includes the D and L forms as separate compounds) comprising the LR nutrient (ref., Fig. 1J-1) is capable of generating up to about 15,000 cpm, and since the positive responses on Mars were typically at or below that count, they were viewed as evidence of the formate-peroxide reaction.

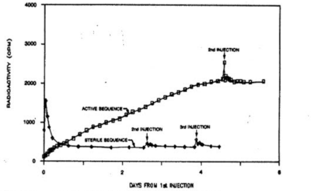


Figure 1J-6: Antarctic Soil No. 664 (pH 8.1) in Viking LR Flight-Like Instrument (23°C)

Testing Peroxide Theory on Mars --Fortunately, we were able to test that theory on Mars. Using a sample that had yielded a low but positive result, we heated it terminally to 50°C. Doing so drove an additional 15,000 cpm out of the soil as illustrated in Figure 1J-7, for a total yield of some 20,000 cpm. Clearly, then, the result exceeded the count possible if only the formate-peroxide reaction were taking place and implies that more than one nutrient was involved in the Mars response.

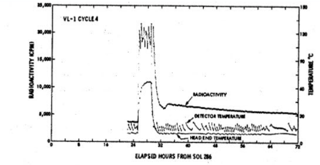
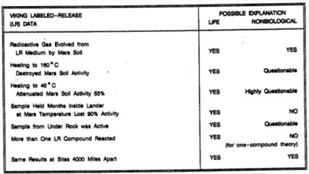


Figure 1J-7: Results From Heated Mars Sample

CONSIDERATIONS AND CONCLUSIONS BASED ON MARS LR RESULTS

It is worth exploring the Mars LR data to see how the facts can best be explained using bio- logical and/or nonbiological arguments. For example, radioactive gas did in fact evolve from the medium, and while this can be attributed to life it might also be due to an unusual physical condition or compound in the soil. In this case, then, each scores a definite Yes as illustrated in Figure 1J-8.



VIKING LABELED-RELEASE (LR) DATA	POSSIBLE EXPLANATION LIFE	NONBIOLOGICAL
Radioactive Gas Evolved from LR Medium by Mars Soil	YES	YES
Heating to 160°C Destroyed Mars Soil Activity	YES	Questionable
Heating to 46°C Attenuated Mars Soil Activity 65%	YES	Highly Questionable
Sample Held Months Inside Lander at Mars Temperature Lost 90% Activity	YES	NO
Sample from Under Rock was Active	YES	Questionable
More than One LR Compound Reacted	YES	NO (for one-compound theory)
Same Results at Sites 4000 Miles Apart	YES	YES

Figure 1J-8: Comparison of Life vs Nonbiological Explanations for Viking LR Data

Control Opportunities --Temperature obviously plays a role in the nature of the response, and control temperatures are particularly worthy of note. Heating a duplicate sample to 160°C destroyed the activity that caused the initial positive response. This satisfies the criteria originally established for the experiment's ability to detect life and it puts a Yes in that column. However, some of the chemical arguments cast some doubt on those initial criteria, hence the nonbiology column can be marked as "questionable" rather than with an absolute No. Heating a sample only to 46°C attenuated the soil activity by 65%, which again is completely compatible with the argument for biology and does not reflect the anticipated behavior for a nonbiology explanation. One would have to score this control a Yes for life and "highly questionable" for the nonbiology argument.

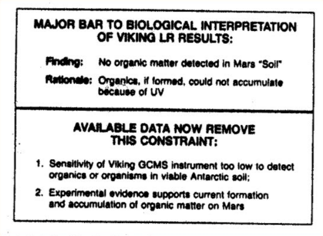
Long-Term Sample Quarantine or Protection --A sample held for a long period of time inside the lander at ambient Mars temperature lost ninety percent (90%) of its previous active response. That kind of reduction does not appear to correlate with any nonbiological theory yet offered, and therefore earns a Yes for the biology argument and a No for the nonbiology argument. The response obtained from soil acquired from beneath (and previously shielded by) a rock again records a Yes for the biology argument, and, at the very least, seriously questions the theory that UV or ionizing radiation was responsible for the positive LR response.

Causal Factors Concerning Type of Response --I believe the probability that more than one LR nutrient compound had to be involved (to produce the total test count already discussed) overpowers the theory that formate alone, reacting with hydrogen peroxide. could have produced our results. Indeed, it renders the nonbiological argument virtually impossible when based on only one nutrient compound. However, the fact that the same results occurred 4,000 miles apart can be equally attributed to living organisms or to a uniform, global distribution of a suspect soil constituent(11). Microorganisms are distributed with surprising uniformity on Earth, relative to similar soils and conditions, and the Viking landing sites on Mars were so similar that they might well support equal microbial populations. In the same sense, however, the similarity of the soil chemistries determined at those sites might allow for similar nonbiological reactions.

The Lack of Organic Chemistry in the Soil

While all of the factors I have just reviewed seem to add up to strong support for a biological explanation, a major negative result remains to be dealt with: the failure to detect organic carbon in Mars' soil (at both Viking lander sites). This fact, coupled with the belief that UV radiation may have precluded the development or existence of organic compounds, suggests that the martian environment is simply too hostile to life.

We believe we have established a sound answer to that constraint, as reflected in Figure 1J-9. Central to our argument is a body of evidence indicating that the sensitivity of the GCMS was too low to detect a very low density of organic compounds in another viable Antarctic soil sample provided by NASA. Further, experimental evidence already alluded to by Dr. Horowitz [NMC-11] strongly supports the probability that organic matter not only forms but accumulates on the surface of Mars in the very face of the UV flux to which it is deemed so vulnerable.



MAJOR BAR TO BIOLOGICAL INTERPRETATION OF VIKING LR RESULTS:

Finding: No organic matter detected in Mars "Soil"

Rationale: Organics, if formed, could not accumulate because of UV

AVAILABLE DATA NOW REMOVE THIS CONSTRAINT:

1. Sensitivity of Viking GCMS instrument too low to detect organics or organisms in viable Antarctic soil;
2. Experimental evidence supports current formation and accumulation of organic matter on Mars

Figure IJ-9: Questionable GCMS Sensitivity for Detection of Low Density Organics

Organic Matter and Life In Test Sample Undetected by GCMS --While reviewing the Mars data, we found still another interesting Antarctic soil sample. Number 726. This sample, also provided for the experimenters by NASA, was brought back and maintained--as in the case of all such samples--in a sealed. pristine condition to preserve its original quality for testing. It had revealed no organic material during such tests in a test-standards GCMS Instrument, but a wet-chemical analysis of the soil showed that it in fact contained 0.03% organic carbon. We had received an aliquot of the same sample in our laboratory. and I found that we indeed had tested it in the LR Instrument.

Figure 1J-10 illustrates the results of that work. Clearly, we had detected living organisms in that soil, and the results of the second injection as well as the sterile controls verified that the response was produced by those organisms. These results, then, reflect a compatible truce between the negative findings of the GCMS and the positive LR results.

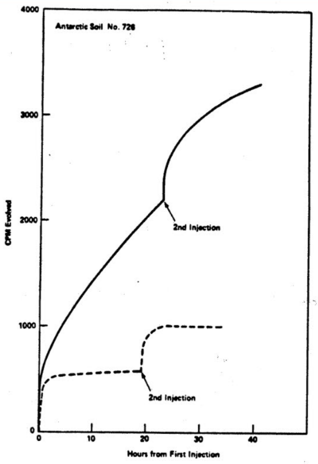
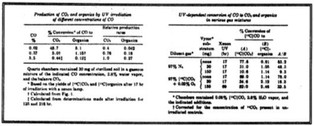


Figure 1J-10: Reactivity of Antarctic Soil No. 726 With LR Nutrient

A ***Link Between UV and Organic Generation*** -- Turning to the questions posed by possible UV effects, an answer has been found in the literature where we should have found it long ago. In his Mars Conference presentation, Dr. Horowitz has described a significant problem he and his group [b] encountered while developing the Viking pyrolytic release (PR) biology instrument, which threatened to remove the experiment from the mission. The substance of the problem, as reviewed in Figure 1 J-11, was that, with Mars light (including UV) shining on Mars atmosphere under simulated martian conditions, organic matter formed and was deposited on the simulated soil particulates. In addition, the organic material continued to accumulate over time. The authors of the paper from which Figure 1J-11 was taken [Hubbard, Hardy, and Horowitz. 1971] stated, "Our findings suggest that UV presently reaching the martian surface may be producing organic matter. ... *the amount of product formed could be considerable over geological time."*



Production of CO_2 and organics by UV irradiation of different concentrations of CO

CO %	% Conversion* of CO to		Relative production rates	
	CO_2	Organics	CO_2	Organics
0.02	48.7	5.1	0.4	0.042
0.37	5.0†	1.15†	0.76	0.18
5.5	0.44‡	0.12‡	1.0	0.27

Quartz chambers contained 30 mg of sterilized soil in a gaseous mixture of the indicated CO concentration, 2.8% water vapor, and the balance CO_2.

* Based on the yields of [^{14}C]CO_2 and [^{14}C]organics after 17 hr of irradiation with a xenon lamp.

† Calculated from Fig. 1.

‡ Calculated from determinations made after irradiation for 135 and 216 hr.

UV-dependent conversion of CO to CO_2 and organics in various gas mixtures

Diluent gas*	Vycor* substratum (mg)	Xenon UV (hr)	% Conversion of [^{14}C]CO to (A) [^{14}C]CO_2†	(B) [^{14}C]-organics	A/B
97% N_2	none	17	77.6	0.91	85.2
	30	17	31.0	1.05	29.5
	150	17	10.6	1.14	9.3
97% [^{14}C]CO_2 + 0.03% O_2	none	17	89.0	1.14	78.0
	30	17	34.6	2.12	16.3
	150	60	82.0	2.46	33.5

* Chambers contained 0.06% [^{14}C]CO, 2.8% H_2O vapor, and the indicated additions.

† Corrected for the concentration of $^{14}CO_2$ present in unirradiated controls.

Figure 1J-11: Photocatalytic Production of Organic Compounds in Mars Simulation (1971)

The problem was resolved in the PA experiment by interposing a filter to screen out UV light below 3,000 angstroms, but that of course does not prevent the phenomenon from occurring on Mars. The formation and accumulation of organic matter under UV light was subsequently confirmed in a paper published in the JACS [Farris and Chen, 1975], in which they demonstrated the production and accumulation of organic material by shining UV light on a mixture of methane and water vapor. They concluded that this phenomenon--the accumulation of organic matter under UV--has "pre-biological significance."

Clearly, then, there is a good case not only for the formation of organic matter in the martian UV environment, but for its accumulation. Indeed, if there is a problem suggested by the body of data produced by the Viking GCMS on Mars, it is the question of why the instrument was unable to detect organic matter that must certainly be there. When considered in perspective with the proven need for greater sensitivity than the Instrument could muster during the analysis of Antarctic sample 726, one must at least agree that the GCMS may have been unable to detect similar densities of organic matter on Mars -- remembering, too, that the terrestrial sample contained living organisms.

Hydrogen Peroxide: Pro and Con

Why, then, were no martian organic chemicals detected when, even without life, their formation on Mars seems so probable? Could they have been overlooked as I have just suggested? Most probably not, **if** the hydrogen peroxide theory prevails with its soritical capacity for converting the LR experiment into a hydrogen peroxide meter. However, we again have found empirical evidence that argues against hydrogen peroxide, this time a product of NASA's Mariner 9 mission (1971-72).

Dr. Straat and I were co-experimenters with R.A. Hanel and others on the Mariner 9 infrared Interferometer spectrometer (IRIS) experiment team. While wrestling with the hydrogen peroxide issue associated with Viking results, I realized that there could be some pertinent data hidden in the product of the Mariner 9 mission. I called Bill Maguire [Goddard Space Flight Center], a NASA scientist formerly associated with the Mariner 9 IRIS work, and asked if there may have been a window provided by the IRIS instrument that could detect hydrogen peroxide. After a brief review of the data, he informed me that there was indeed an excellent window for hydrogen peroxide -- and that none had been found.

A Review of Nonbiological Hypotheses

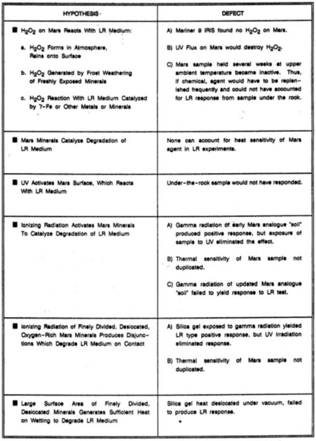
Figure 1J-12 (a and b) presents a compilation of all the hypotheses that attempt to explain the LR results in a non biological manner, and which have been published or otherwise called to our attention. The first, of course, is the hydrogen peroxide theory (which also represents several subset theories), and it includes a rationale for how peroxide forms and exists on Mars.

Because the Mariner 9 IRIS instrument found no trace of hydrogen peroxide on Mars, one can at least presume that if it is there at all it must be present only in extremely small amounts. And, because of the amount of atmospheric water vapor detected by the Viking orbiters in the vicinity of the landing sites, any small amount of hydrogen peroxide that may have been missed by Mariner 9 would somehow have to survive a confrontation with up to 5,000 times its own volume in atmospheric water(12); if water vapor immediately reacts with hydrogen peroxide, as Dr. Horowitz has explained, the hydrogen peroxide would not have been present. If water vapor doesn't do the job, one should remember that hydrogen peroxide is light-labile and especially vulnerable to virtually immediate destruction by UV radiation(13), or that contact with iron or other possible metal catalysts in the surface material (aided by atmospheric water vapor) is also capable of destroying it. Assuming either or all of these destruction scenarios to be active on Mars, one is driven to conclude that any hydrogen peroxide that somehow managed to find its way into the martian soil would certainly have been destroyed long before it could be picked up by a Viking surface sampler and exposed to our LR nutrient.

Other nonbiology theories involve: minerals that catalyze the reactions with the LR nutrients, ultra-violet radiation (already discussed), ionizing radiations of various kinds. finely divided and desiccated oxygen-rich minerals, and large surface areas of fine particulate generating heat of hydration upon wetting. We and others have tested all of these proposals, and none of them could provide a fully satisfactory explanation for--or a duplication of--the provocative responses we got from the LR experiment on Mars. If we can't evoke a tenable hypothesis for a chemical or physical reaction that can duplicate the Mars results after ten years, perhaps it is finally time to consider the biological explanation we were looking for in the first place. Perhaps, after all, we did indeed detect life on Mars.

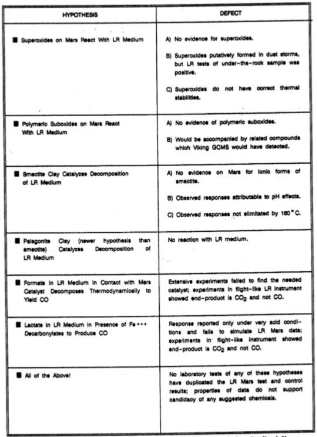
A CASE FOR LICHEN ON MARS

We have a natural model for one possible martian life form close at hand --lichen. In fact, the lichen possibility was offered as a model for martian life long ago, and such organisms possess all the characteristics necessary for survival in the harsh martian environment. They serve as a good model for Mars life because their known characteristics satisfy virtually all of the criteria imposed by the nature of the results in both Viking LR experiments. on Earth. Lichens are the pioneers of vegetation and are frequently credited with the initiation of weathering over large areas.



HYPOTHESIS	DEFECT
■ H_2O_2 on Mars Reacts With LR Medium: a. H_2O_2 Forms in Atmosphere, Rains onto Surface b. H_2O_2 Generated by Frost Weathering of Freshly Exposed Minerals c. H_2O_2 Reaction With LR Medium Catalyzed by ?-Fe or Other Metals or Minerals	A) Mariner 9 IRIS found no H_2O_2 on Mars. B) UV Flux on Mars would destroy H_2O_2. C) Mars sample held several weeks at upper ambient temperature became inactive. Thus, if chemical, agent would have to be replenished frequently and could not have accounted for LR response from sample under the rock.
■ Mars Minerals Catalyze Degradation of LR Medium	None can account for heat sensitivity of Mars agent in LR experiments.
■ UV Activates Mars Surface, Which Reacts With LR Medium	Under-the-rock sample would not have responded.
■ Ionizing Radiation Activates Mars Minerals To Catalyze Degradation of LR Medium	A) Gamma radiation of early Mars analogue "soil" produced positive response, but exposure of sample to UV eliminated the effect. B) Thermal sensitivity of Mars sample not duplicated. C) Gamma radiation of updated Mars analogue "soil" failed to yield response to LR test.
■ Ionizing Radiation of Finely Divided, Desiccated, Oxygen-Rich Mars Minerals Produces Disjunctions Which Degrade LR Medium on Contact	A) Silica gel exposed to gamma radiation yielded LR type positive response, but UV irradiation eliminated response. B) Thermal sensitivity of Mars sample not duplicated.
■ Large Surface Area of Finely Divided, Desiccated Minerals Generates Sufficient Heat on Wetting to Degrade LR Medium	Silica gel heat desiccated under vacuum, failed to produce LR response.

Figure 1J-12: Defects in Nonbiological Hypotheses for Viking LR Results (1 of 2)



HYPOTHESIS	DEFECT
■ Superoxides on Mars React With LR Medium	A) No evidence for superoxides. B) Superoxides putatively formed in dust storms, but LR tests of under-the-rock sample was positive. C) Superoxides do not have correct thermal stabilities.
■ Polymeric Suboxides on Mars React With LR Medium	A) No evidence of polymeric suboxides. B) Would be accompanied by related compounds which Viking GCMS would have detected.
■ Smectite Clay Catalyzes Decomposition of LR Medium	A) No evidence on Mars for ionic forms of smectite. B) Observed responses attributable to pH effects. C) Observed responses not elimitated by 160 °C.
■ Palagonite Clay (newer hypothesis than smectite) Catalyzes Decomposition of LR Medium	No reaction with LR medium.
■ Formate in LR Medium in Contact with Mars Catalyst Decomposes Thermodynamically to Yield CO	Extensive experiments failed to find the needed catalyst; experiments in flight-like LR instrument showed end-product is CO_2 and not CO.
■ Lactate in LR Medium in Presence of Fe+++ Decarbonylates to Produce CO	Response reported only under very acid conditions and fails to simulate LR Mars data; experiments in flight-like instrument showed end-product is CO_2 and not CO.
■ All of the Above!	No laboratory tests of any of these hypotheses have duplicated the LR Mars test and control results; properties of data do not support candidacy of any suggested chemicals.

Figure 1J-12b: Defects in Nonbiological Hypotheses for Viking LR Results (2 of 2)

Lichen can: 1) grow on bare, unweathered desert and mountain top rocks in extremely hot or cold environments, 2) protect themselves from UV radiation, 3) withstand long-term desiccation, and 4) absorb water from atmospheric vapor. In addition to being able to grow on bare rocks in inhospitable regions, they exhibit "endolithic" capability -- growing and surviving *within* rocks.

It should be noted that many forms of terrestrial biota could inhabit Mars but for the apparent lack of liquid surface water and the difficulty in husbanding water from the atmosphere against the low vapor pressure. However, we should not close our eyes to the latter possibility. In juxtaposition, one might well imagine martian scientists looking down on Earth and saying: "There can't be any plants or trees on that poor planet, there is only 125 parts-per-million of carbon in the atmosphere!" I think the arguments are fairly comparable. We have found that lichen organisms can essentially--quite satisfactorily, in fact--replicate the LR results in all respects. And, while it is not appropriate to get into the details of these studies here, I will present some photographic material that suggests to us (under very close scrutiny) that the Viking lander images may in fact have provided evidence of lichen growth on Mars.

Possible Evidence of Lichen on Mars

Figure 1J-13 presents two images of a rock known as Patch Rock at the VL-1 (Chryse Planitia) site. The image was produced at JPL by the image reproduction system developed specifically for the precise production of Viking lander images from digital data transmitted back to Earth from Mars. In this picture pair, one can see for the first time a hint of something not monotonously orange-red, as initially reported about Mars. Instead, greenish patches are seen on some of the small rocks. We found that the configurations of the patches changed over a period of time. The picture on the left was taken on sol 28/VL 1 and the one on the right was taken sol 615/VL1(14). A lot had of course happened over the intervening 587 sols which affected the character of the site; there had been some digging by the lander's surface sampler and there had been a dust storm. However, the intensification of the greenish color and a change in the appearance of the rock's patch was not readily explained by these events.

Spectral analyses were made of these images at JPL, and the patches proved to be the greenest and least color-saturated objects in the field of view. Figure 1J-14 illustrates the results of a color-saturation analysis involving the same rock, this time using pictures taken sol 1/VL1 and sol 302/VL1. A change in the response over time was evident, and, of all the features in the field of view (of whatever color), the spots and patches highlighted were the least color saturated. I should point out, incidentally, that lichens come in many colors: red, yellow, pink, gold --even white, black, and colorless. The presence of greenish colored patches were subsequently verified by others [1979c].

Lichen Detection Tests With Viking STL Imaging System

Because Viking mission operations were still underway as we were conducting these initial analyses, we took some lichen-bearing rocks to JPL and put them in a simulated Mars terrain model that had not yet been dismantled(15). We took pictures of them using the science test lander (STL) Imaging cameras (identical to the flight cameras), and Figure 1J-15 presents the results of that work (top); the picture at the bottom is a conventional photograph of the modeled terrain for the landing site, which included highly detailed foam duplicates of rocks at the site (painted to look like the real rocks). The greenish lichens on our sample rocks were less clearly visible than in Earth sunlight and resembled the Mars images. When we subjected these pictures to a color-saturation analysis similar to the one I spoke of in reference to the actual Mars images, the Earth lichens were again the least color-saturated objects in the field of view.

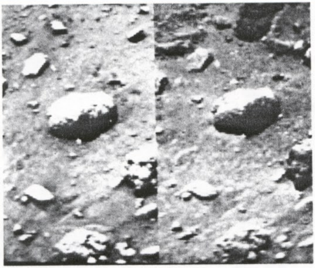


Figure 1J-13: "Patch Rock" at VL-1 Site (left, sol 28; right, sol 615)

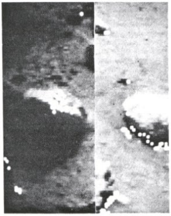


Figure 1J-14: Areas of Lowest Color Saturation (based on computer analysis of data)

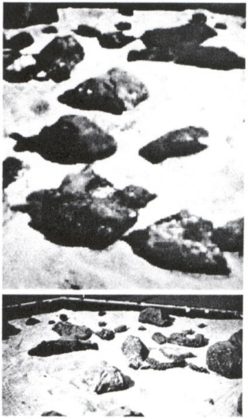


Figure 1J-15: Viking Test Image of Terrestrial Rock Lichen (top)
STL Test Scene (bottom)

Antarctic Rock Correlates With Mars Results --Working in the Antarctic, Friedmann and Ocampo [1976] discovered that there were living organisms--algae and lichen--below the surface of many porous sandstone rocks(16). These organisms are typically found at a depth of about 1 to 1.5 cm and are somehow "eking" out a living inside these Antarctic rocks, with very little sunlight or water able to penetrate to their depth. Indeed, they seem almost to be hiding from it, and it is in fact likely that they have evolved their retreat from rock surfaces to escape the harshness of the Antarctic environment. In Figure 1J-16, a relatively common sample of rock with surface lichen is compared with a sample of Antarctic rock, the latter split to reveal the lichen-bearing layer beneath its surface (dark band along top of exposed face).

Drs. Friedmann and Ocampo were kind enough to bring one of the Antarctic rocks to our laboratory, where we carefully split it to reveal a green band about 1.5 cm below the surface. We then aseptically scraped out about 25 milligrams for testing in the LR experiment. To facilitate a comparison, Figure 1J-17 (bottom, right) illustrates the results of these with plots reflecting both active and sterile Mars data acquired by VL-2 in Utopia Planitia. The similarity is remarkable, and we contend that these data must certainly be considered in the realm of contributing evidence.

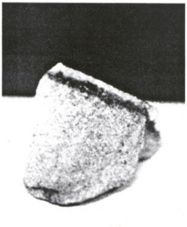


Figure 1J-16: Lichen Examples --
(above right) Antarctic
Subsurface Lichen;
(below) Common Rock Lichen

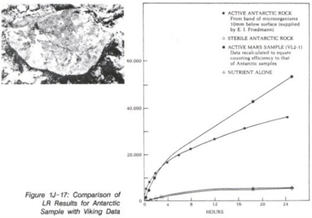
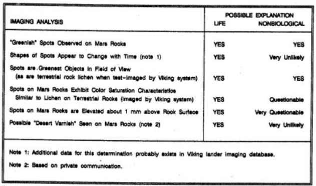


Figure 1J-17: Comparison of LR Results for Antarctic Sample with Viking Data

Summary Results of Imaging Experiments -- In Figure 1J-18, we have summarized the results of the imaging study in the same manner as the previous summary of the LR data (Fig. 1J-8). The greenish spots or patches could be attributed to life; alternatively, chemicals or minerals could be responsible. The changing configuration of the patches with time, however, is strongly suggestive of life and is not easily explained by mechanical or meteorological events.



IMAGING ANALYSIS	POSSIBLE EXPLANATION LIFE	POSSIBLE EXPLANATION NONBIOLOGICAL
"Greenish" Spots Observed on Mars Rocks	YES	YES
Shapes of Spots Appear to Change with Time (note 1)	YES	Very Unlikely
Spots are Greenest Objects in Field of View (as are terrestrial rock lichen when test-imaged by Viking system)	YES	YES
Spots on Mars Rocks Exhibit Color Saturation Characteristics Similar to Lichen on Terrestrial Rocks (imaged by Viking system)	YES	Questionable
Spots on Mars Rocks are Elevated about 1 mm above Rock Surface	YES	Very Questionable
Possible "Desert Varnish" Seen on Mars Rocks (note 2)	YES	Very Unlikely

Note 1: Additional data for this determination probably exists in Viking lander imaging database.

Note 2: Based on private communication.

Figure 1J-18: Summary of Image/Spectral Analysis Relative to Lichen Possibility

In summary, then, we feel that the evidence produced during the imaging studies thus far undertaken is more indicative of life than of chemistry or physics. In the near future we hope, and have so proposed, to try to resolve this problem through access to additional image data being maintained in the Viking database.

SUMMATION AND CONCLUSIONS

We have waited ten years for all of the theories, experiments and results produced by the many scientists investigating our experiment to be reviewed before voicing a committed conclusion of our own. After examining these efforts in great detail, and after years of laboratory work trying to duplicate our Mars data by nonbiological means, we find that the preponderance of scientific analysis makes it more probable than not that living organisms were detected in the LR experiment on Mars. This is not presented as an opinion, but as a position dictated by the objective evaluation of all relevant scientific data.

In conclusion, then, we submit that this real possibility for martian biology should be an important--even dominant--consideration in the future exploration of Mars. This clearly is not the case at the present time, according to published NASA plans for continuing the unmanned exploration of Mars which neglect the biology issue. The search for life on Mars, when evidence for its possible existence offers such important potential, should have much greater significance for the planning of such missions.

REFERENCES

References identified here by alphabetically sequenced lower-case characters are keyed to *specific* references in the presentation text where the same characters are used as identification tags. In the text, however, the identifier will be found within brackets, either by itself or with a name and/or credit date (i.e., when formally published) --e.g., [a] or [1978a].

NOTED PRESENTATION REFERENCES (see following page for additional references)

[a] Cameron, R.E., King, J., and Daird, C.N. 1970. *Antarctic Ecology,* Vol. 2, p. 202 (Holdgate, ed.), London.

[b] Hubbard, J.S., Hardy, J.P., and Horowitz, N.H. 1971. *Proc. Nat. Acad. Sci.* 3:574-578.

[c] Strickland, E.L., III. 1979. NASA Tech. Memo. 80339.

[d] Guiness, E., et al. 1979. NASA Tech. Memo. 80339.

(1) Because the original title alluded to was incorrectly reflected in the conference agenda, it was not used in this proceedings document. {Ed.}

(2) Dr. Patricia A. Straat was Dr. Levin's principle colleague during the development, testing, and mission operation/analysis work associated with the Viking biology LR experiment. In addition, she worked with Dr. Levin and others on the Mariner 9 IRIS experiment. {Ed.}

(3) The Viking biology package was remarkably miniaturized. It contained--in one small complex box--three independent experiments designed to detect possible life processes in the martian soil (based on different models of Mars). The package itself. weighing only about 33 pounds and measuring 11.5 x 13.5 x 10.75 inches (with a volume of 1.669 in.^{3}), was built by TRW. In addition to the labeled-release experiment. the instrument also contained gas-exchange and pyrolytic-release experiments. a complex array of plumbing and electrical circuitry, and the necessary mechanics to facilitate soil processing and distribution. Each of the experiments was capable of four cycles. and all of the experiments in both landers were successfully operational on Mars, experiencing few instrument problems and no failures. {Ed.}

(4) The labeled-release (LR) experiment had its origin in 1959 when Dr. Levin first proposed and then--in 1960--began development of a self-sufficient sample acquisition and analysis instrument called Gulliver. It was to fly on what was then called the Voyager (Mars) spacecraft, it didn't, of course, because that Voyager program was canceled and then scaled down to become the Viking Project. However, Gulliver was not wasted; its essential elements served as the precursor for the Viking biology instrument's labeled-release (LR) experiment discussed in this presentation, {Ed.}

(5) Viking Lander 1 (VL-1) landed in Chryse Planitia (at 22.5°N, 48°W) on July 20,1976. {Ed.}

(6) Each Viking lander was equipped with two plutonium-fueled, AEC SNAP-19 Radioisotope Thermoelectric Generators (RTG's), mounted atop the landers and protected by windscreens. The RTG's were capable of producing 35 W each (total output of 70 W per lander), and were used to provide both direct power and recharging power for two internal wet-cell, nickel-cadmium battery packs (two 28vdc, 24-cell batteries in each pack). RTG's facilitate non-solar-dependent power for very long periods, and VL-1 survived into late 1981. {Ed.}

(7) Viking Lander 2 (VL-2) landed in Utopia Planitia (at 44°N, 226°W) on September 3, 1976. {Ed.}

(8) A temperature of 50°C (122°F) is very warm for an otherwise cold planet (compared to Earth). The Viking landers recorded daytime temperatures in the –25°C to –35°C range, dropping at night to –85°C to –90°C during the martian summer. However, it is believed that temperatures at the very surface may, in some areas (e.g., equatorial regions), be significantly warmer (25°C+). This potential is enhanced when correlated with higher atmospheric pressures and/or the presence of water vapor associated with some topographic features. {Ed.}

(9) A "sol" is one solar day for Mars, While a martian day is comparable in length to an Earth day, it is somewhat longer ($24^h37^m22^s$). This requires that sols rather than Earth days be used as an independent chronological reference when the planet's axial rotation is a pertinent factor in a given consideration. This, of course, is particularly true at the surface of Mars where darkness prevails at night just as on Earth. {Ed.}

(10) Antarctic Sample No. 664 was a bonded and certified NASA-supplied soil given to experimenters to test their instruments during the development of the Viking biology experiments. Such samples were stored, sealed, and maintained in their pristine condition for testing purposes.

((11) It is believed that weathering and meteorology over time on Mars is responsible for a homogeneous and generally uniform distribution of the planet's surface chemistry. {Ed.}

(12) The limit of sensitivity for the Mariner 9 IRIS experiment, relative to its ability to detect hydrogen peroxide, was 1×10^{-2} precipitable microns. By comparison, the water vapor measured above both Viking landing sites by the orbiters' IR water vapor mapping instruments ranged up to about 50 precipitable microns. {Ed.}

(13) The reaction coefficient for the UV destruction of H_2O_2 exceeds that of its formation by 10^6.

[14] Because martian days (sols) are longer than Earth days, they do not correlate directly with Earth days. For example, a martian year is 669 sols compared to 687 Earth days. Viking lander operations are typically considered in terms of the number of sols elapsing from the first day of each landing, such that the sol count for each lander is different. Sol 1 for VL-1 is July 20. 1976, while Sol 1 for VL-2 is September 3. And. because there is a difference of more than 40 sols. It is necessary to know which lander is in reference for a given sol number -- hence the use of "/VL1" or "/VL2" with sol numbers used in this presentation. Sol 615/VL1, for example, represents the 615th martian day of VL-1 operations. {Ed.}

[15] The Viking science test lander (STL) was used at JPL during mission operations to program and test actual command sequences (for directing the cameras and soil samplers on the Mars landers) before transmitting them to the specified lander. Each landing site, therefore, had to first be modeled very precisely with accurate reproductions of the surface material, very small elevation variations (including trenches ultimately dug by the samplers) and rocks -- particularly those within range of the soil sampler. Each of the STL's two cameras could image like its counterpart on each of the Mars landers, such that complete imaging sequences could be tested for errors prior to transmission. {Ed.}

[16] Dr. E. Imre Friedmann, a biology professor and director of the Polar Desert Research Center at Florida State University (Tallahassee), is credited with the first discovery of organisms living within rocks [1964] while studying rocks from Israel's Negev desert. His Antarctic research was funded jointly by NASA and the National Science Foundation. {Ed.}

UNSPECIFIED REFERENCES OF INTEREST

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Levin, G.V., and Straat, P.A. 1976a. Labeled release--an experiment in radiospirometry. *Origins of Life.* 7:293-311.

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Ed. Note: Vol. 82, No. 28 (pages 3959-4681) of J. Geophys. Res. (item 4 above) was a complete publishing of the Viking Primary Mission results (with early Extended Mission results), i.e., those results of Viking mission activity during the last half of 1976 and early 1977 that could be properly reported by mid 1977 (publish date was September, 1977). The results of--and early conclusions associated with--the Viking biology experiments are included. The results and conclusions are also modestly reviewed by H.S.F. Cooper (The Search for Life on Mars, item 1 above) as the author describes the activity and interaction of the Viking biology team's key characters, as well as the evolution and product of their work, against the backdrop of Viking mission activity. Similarly, ON MARS: Exploration of the Red Planet -1958-1978 (E.C. Ezell and L.N. Ezell, 1984, NASA SP-4212 in the NASA History Series), presents a thorough historic account of the Viking Project and includes a conservative. nontechnical overview of its science results.