STEALTH LIFE DETECTION INSTRUMENTS ABOARD CURIOSITY

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ABSTRACT

NASA has often stated (e.g. MSL Science Corner[1]) that it's Mars Science Laboratory (MSL), "Curiosity," Mission to Mars carries no life detection experiments. This is in keeping with NASA's 36-year explicit ban on such, imposed immediately after the 1976 Viking Mission to Mars. The space agency attributes the ban to the "ambiguity" of that Mission's Labeled Release (LR) life detection experiment, fearing an adverse effect on the space program should a similar "inconclusive" result come from a new robotic quest. Yet, despite the NASA ban, this author, the Viking LR Experimenter, contends there are "stealth life detection instruments" aboard Curiosity. These are life detection instruments in the sense that they can free the Viking LR from the pall of ambiguity that has held it prisoner so long. Curiosity's stealth instruments are those seeking organic compounds, and the mission's high-resolution camera system. Results from any or all of these devices, coupled with the Viking LR data, can confirm the LR's life detection claim. In one possible scenario, Curiosity can, of itself, completely corroborate the finding of life on Mars. MSL has just successfully landed on Mars. Hopefully, its stealth confirmations of life will be reported shortly.

Introduction

The spacecraft Curiosity has successfully landed on Mars. This is NASA's largest planetary effort. However, while the search for life beyond the Earth remains a prime priority of NASA, Curiosity has no life detection experiment. In the 36 years since Viking's landing, July 20, 1976, NASA has not sent another life detection experiment to Mars; indeed, life detection experiments have been specifically prohibited. The plan, instead, has been to examine a sample of Martian regolith brought to Earth, an event probably decades in the future. Despite this long deferment in its quest, NASA's Director of the Mars Exploration Program, Doug McCuistion, recently said[2], "Seeking the signs of life still remains the ultimate goal." That goal may be nearer at hand than NASA indicates. **In the author's opinion, highly sensitive instruments aboard Curiosity have the capability of confirming that the Viking Labeled Release experiment did detect living microorganisms on the surface of Mars.**

Background

The LR's claim[3] to life is based on responses obtained when a ^{14}C labeled nutrient solution was applied to samples of Martian soil. Strong evolution of ^{14}C-labeled gas(es) occurred immediately following injection of the nutrient, and continued in a pattern, in both amplitude and kinetics, very similar to that obtained from many LR tests of terrestrial soils. On Mars, as on Earth, confirmation of the biological nature of a positive result was sought by heating a duplicate sample to a temperature to kill or impair microorganisms, but not high enough to destroy soil chemicals that might have reacted with the nutrient compounds. All such control tests on Mars indicated microorganisms, not chemicals, as the source of the active responses[4]. Table 1 summarizes the Martian results.

TABLE 1

SUMMARY OF VIKING LR MARS RESULTS

Positive responses were obtained from soils at both Viking landers
Soil* heated to 160° C for three hours produced nil response
Soil** heated to 51° C for three hours prior to testing produced several small sporadic peaks (5%-10% of positive response) each of which was further reduced by approximately 90% prior to the start of the next peak
Soil** heated to 46° C for 3 hours produced kinetics similar to positive response, but 70% reduced in amplitude
Soils maintained two and three months, respectively, in the VL1 and VL2 soil distribution boxes, in dark, at approximately 7-10° C, under ambient Mars atmosphere, pressure and humidity, produced nil responses
Soil** protected from UV by overlying rock produced typical active response
Upon second injection of nutrient, approximately 20% of gas already evolved was re-absorbed into the soil, and gradually re-evolved over period of two months, unusual for most LR tests on Earth, but similar to a test of an Antarctic soil
*Run at VL1 only. ** Run at VL2 only.

Subsequently, independent approaches[5, 6] indicated a circadian rhythm in the LR data, thereby supporting a biological conclusion. Most recently, an entirely new

approach[7], based on complexity analysis of the LR data, produced a result that strongly favored biology.

Over the years since Viking, many theories have attempted to explain away the biological nature of the LR. No experiment or theory has survived scientific scrutiny, nor has any experiment been able to duplicate the LR responses and controls without using living organisms[8]. Principal among the arguments against life has been the failure of the Viking organic analysis instrument (GCMS – gas chromatograph-mass spectrometer) to detect any organic matter in the same soil samples from which the LR got its life responses. Although researchers[9, 10] have demonstrated deficiencies in the Viking GCMS that impugn its negative result, the presumed lack of organics remains the only substantial barrier to general acceptance of the LR claim.

In an early attempt to resolve the issue raised by the Viking LR, the author examined all lander images taken at Viking sites 1 and 2. He reported[11] finding colored patches, ranging from ochre to yellow to greenish, on some of the foreground rocks. Six channel spectral analyses of the patches found that their color, hue and intensity closely matched those same parameters of terrestrial lichen as analyzed by the Viking Lander Imaging System. However, resolution of the Viking images was too coarse to support any claim to life based on optical spectral analysis alone.

<u>Curiosity's Stealth Life Detection Instruments</u>

While none of the extensive array of Curiosity's Mars Surface Laboratory (MSL)[12] can detect life, several of its instruments can produce results that could confirm the Viking LR's claim to have discovered Martian endogenous life. Coupled with the Viking LR data, they, thus, may be termed life detection instruments. They are shown in Table 2.

Table 2. Curiosity's "Stealth" Life Detection Instruments

Sample Analysis at Mars (SAM) has the following components that can execute life-pertinent analyses:

Oven – this can heat samples to 1,000° C. The vapors and gases produced can be sent to:

Quadrupole Mass Spec (QMS)[13]. The QMS can identify organic compounds obtained from the soil. It can also analyze the Martian atmosphere for organic compounds. It is sensitive to the sub ppb level. The stated range of molecular weights is 2 – 235 Da. SAM will likely use techniques[14] that process data to identify much heavier organic molecules, such as peptides and proteins. The QMS can also determine the isotope ratios of C, H and O and their respective abundances.

Gas Chromatograph (GC)[15]. The GC can identify specific gases separated by the QMS.

Tunable Laser Spectrometer (TLS). The TLS can analyze atmospheric components, and can determine isotopic ratios of atom constituents of CO_2 and CH_4, which ratios, it has been proposed, can distinguish between biological and chemical origin of these gases. However, this could not determine whether any biological indication came from living or dead organisms.

Cameras – a system of cameras is carried aboard.

MastCam. Two cameras are mast mounted. They take images in true color, and have auto focus ranging from 2 m to infinity. They can take high definition videos. They are equipped with a Hand Lens System, also imaging in true color, with resolutions up to 14.5 um per pixel. Focus of the Hand Lens System is from mm distances to infinity. In addition, there is a Microscopic Probe, capable of color imaging with a spatial resolution down to three pixels (um).

ChemCam. This is a truly novel and potent innovation, termed "laser-induced breakdown spectroscopy." A laser gun is fired at a selected target. The action vaporizes some of the rock material. The vapor produced is then remotely and instantly analyzed in its visible, near-UV and near-IR spectra. The instrument has a 20 cm field of view, within which it can resolve a target as little as one mm in diameter at a distance of 10 m.

The Case for Organic Matter on Mars.

Despite the failure to find any organic compounds in the surface material or atmosphere of Mars by the only instrument to report on such, the Viking GCMS[16], circumstantial evidence overwhelmingly indicates both the deposition and formation of organic matter on Mars. Further, the Viking GCMS has been found wanting in that it did not pyrolyze its soils samples at a sufficiently high enough temperature[17], and that the presence of perchlorates in the soil samples may have obliterated any trace of organics.[18] It seems certain that organic matter was deposited on Mars, as it was on Earth, by comets, meteors and meteorites, impacting densely in the years soon after formation of the planets, and, at greatly reduced frequency, continuing to this day. Also, Mars, again like Earth, must be receiving thousands of tons or organic matter deposited annually by interplanetary dust particles.

In addition to receiving organic matter from space, there is strong evidence that Mars manufactures its own. This evidence comes from the Viking Pyrolytic Release (PR) [19] life detection experiment. The PR sought to measure carbon assimilation by living microorganisms by exposing Martian soil to simulated Martian sunlight in a chamber containing the 7 mb Martian atmosphere to which its CO_2 and CO was supplemented with 2.5 mb of $^{14}CO_2$ and ^{14}CO in a ratio of 15:1, respectively. In the analysis phase, a statistically significant level of radioactivity in the soil organics would be evidence of assimilation. On Mars, the PR yielded tantalizing results that for a short time were considered presumptive evidence of biology. However, the low absolute value of the signal, while significant over the radioactive background, and the still-positive result of the heated ("sterilized") control supported a non-biological interpretation.[20]

The paper[21] claiming that the LR detected life also showed that the Viking Pyrolytic Release (PR) experiment had discovered that organic material was actually being photochemically synthesized on current Mars. This might be thought of as a Miller-Urey experiment on the endogenous Martian atmosphere. Not only did organic compounds form, they survived in the soil sample for the five-sol experimental cycle. This survival rebutted the oft-cited claim that the surface of Mars was so oxidative that it would destroy any life and organic matter, thereby explaining the generally perceived absence of both. Accumulation of organic matter under Martian ambient conditions was demonstrated within the PR instrument. This production of organics on Mars should have been anticipated from the pre-Viking work[22, 23].

The on-going production of organic matter on Mars was again demonstrated in post-Viking studies[24], but, strangely, was not appreciated as the major finding it was, confirming the indigenous formation and survival of organic matter on Mars. While stating[25] that, "The results are startling," the PR experimenters then minimized their finding by saying, "If organic Matter is being synthesized on Mars, it does not accumulate above the sensitivity threshold of the GCMS." They, thus,

succumbed to the reputed sensitivity of the Viking GCMS, ignoring the survival of the organic matter formed in the PR, which indicates the organics must continue to accumulate well beyond that level. In fact, the PR results should have been immediately recognized as a strong indication that the Viking GCMS was not working properly.

Last year, the author called this matter to the attention of Dr. Jerry S. Hubbard, Co-Experimenter on the Viking PR. Dr. Hubbard then went into his files and produced unpublished data from his laboratory work on the production of photocatalytically synthesized organic compounds from simulated Martian atmosphere under simulated sunlight. Formic acid, formaldehyde, acetaldehyde and glycolic acid comprised about 85% of the ^{14}C-products, with the remainder being unidentified compounds. Hubbard's previously unpublished data presented in Table 3 show the yields of photocatalytic synthesis products on three model Mars soils irradiated with simulated Mars sunlight. Low levels of abiotic synthesis were also detected in post-Viking studies[26] with the standard PR removal of UV frequencies below 320 nm. Hubbard[27] calculated the carbon assimilated in three light, dry incubations of the Martian Chryse soils[28]. The Viking data correspond to 10.5, 2.9 and 3.6 pmoles of organic carbon, if produced from ^{14}CO, or 37.9, 10.7 and 12.3 pmoles, if produced from $^{14}CO_2$.

In the Viking PR instrument, an optical filter was installed which removed wavelengths ≤ 320 nm from the light source The filtered light was much less effective in driving the abiotic synthesis of simple organics, thus reducing the possibility of a false positive result. Accordingly, the light in the PR instrument on Mars was not a true simulation of sunlight there. The new data in Table 3 show that, when the light used simulates the Martian flux, some 3 orders of magnitude more organic matter is formed over the amount formed in the UV-protected PR on Mars.

However, it is important to point out that the organic compounds produced in the PR were of relatively small molecular size. Hence, they provide no direct evidence for biology-sized molecules on Mars. Nonetheless, these repetitive and consistent results raise a strong challenge to the negative findings of the Viking GCMS. Added to the previously stated sources of organic matter on Mars, they leave little doubt that MSL will find organic compounds in the soil of Mars.

TABLE 3

Photocatalytic Synthesis of Organics on Model Mars Soils using Simulated Mars Sunlight

Sample[a]	Irradiation[b]	nmoles of carbon recovered		
		Gas phase[c]		Soil extract[d]
		^{14}CO	$^{14}CO_2$	^{14}C-organics
Volcanic ash shale	7 day	13.5	17.3	117.0
Mars analog soil	7 day	93.9	32.0	10.8
Montmorillonite	3 day	106.9	31.9	13.4

[a] Samples(300 mg) in 5.5 ml quartz tubes were predried at 145°C for 16 hr and then attached to a vacuum/gas mixing apparatus while still hot. Sample tubes were filled with CO_2 and evacuated five times.
[b]The evacuated tubes were filled with 320 torr of $^{12}CO_2$ and 0.5 torr of ^{14}CO(145 nmoles) and then mounted horizontally on a wheel which rotated at 2 rpm. With the light path perpendicular to the axis of rotation samples were irradiated with a high pressure xenon source filtered through 2.5 mm Vycor glass, which removed UV < 220 nm, with the sample incident light approximating the flux on the Martian surface. The maximum and average intensities reaching the samples were 30 and 17 $mW \cdot cm^{-2}$.
[c] Gases were separated and their radioactivity quantified[29].
[d]Samples were extracted in boiling water and radioactivity quantified[30].
Credit: Dr. Jerry S. Hubbard.

The most rapid and efficient conversion occurred on the volcanic ash shale where 81% of the 145 nmoles of available carbon in CO and 87% of the carbon in the consumed CO were recovered in the organic products in the soil. With the Mars analog soil the conversion values relative to the available CO and the consumed CO were 7.4% and 21%, respectively. For montmorillonite after the 3-day irradiation, 35% of the carbon in the depleted CO was recovered in the soil organics. Hubbard states, "*Any one of the three diverse model soils would be an effective substratum for the abiotic synthesis on Mars.*" Beyond this Mars-specific evidence, a very recent paper[31] makes the case for the formation of complex organic matter throughout all planetary systems, including our solar system. Thus, the stage seems set for Curiosity to find even complex organics on Mars near or on the surface. Another recent paper[32] estimates that complex organic molecules as little as only several cm beneath the surface of Mars can survive cosmic radiation, thus being readily available for detection by Curiosity's MSL.

Biological Relevance of SAM's Findings. SAM's QMS, GC and TLS have the ability to detect organic compounds that would be present in soils even sparsely populated with microorganisms, well within the reach of the LR's sensitivity (some 10 cells). Moreover, with the inductive analytical technique cited above for the QMS, any gases detected could be established as having come from specific peptides, proteins or other large molecules of biological relevance. The GC and the TLS can also make such determinations. Furthermore, the isotopic analysis and ratios of the isotopes of carbon and hydrogen in any methane found can be indicative of a chemical or biological origin of the methane. Add the extraordinary power of the ChemCam, with its broad spectroscopic capabilities, and it is apparent that the MLS can finally settle the long-standing issue of whether or not there are organics on Mars. It can also establish whether there are organic compounds present that are commonly associated with biological activity on Earth. In themselves, as NASA has said, such findings would not be proof of life.

Complex organic molecules have often been stated to be "biomarkers," meaning that their detection would be conclusive evidence for life. However, it is likely that, were even DNA found, such "evidence" would be quickly relegated to the dust bin of doubt by Occam's razor.[33] All such evidence will be deemed as more likely to have occurred through abiotic happenstance rather than having required the development of a living entity to produce it.

The unintended and highly significant outcome of Curiosity's search would be its confirmation of complex organic compounds on Mars. This finding would remove the last, lingering support from the dwindling, but remaining consensus that the Viking LR results are not proof of life. The LR results are not a snapshot, as are the "biomarkers," but are long-term, continuous evidence of metabolism, as confirmed by metabolism-killing controls. Objectors would be driven to the sometimes proposed concept that chemistry on Mars differs from chemistry on Earth, that some mysterious reaction, not yet achievable in laboratories, is mimicking life. This would be a difficult case to make before competent chemists and physicists.

Visual Evidence for Life.

The radiometric ("true color") image of the Viking 1 landing site, Figure 1, shows many interesting features and colors.

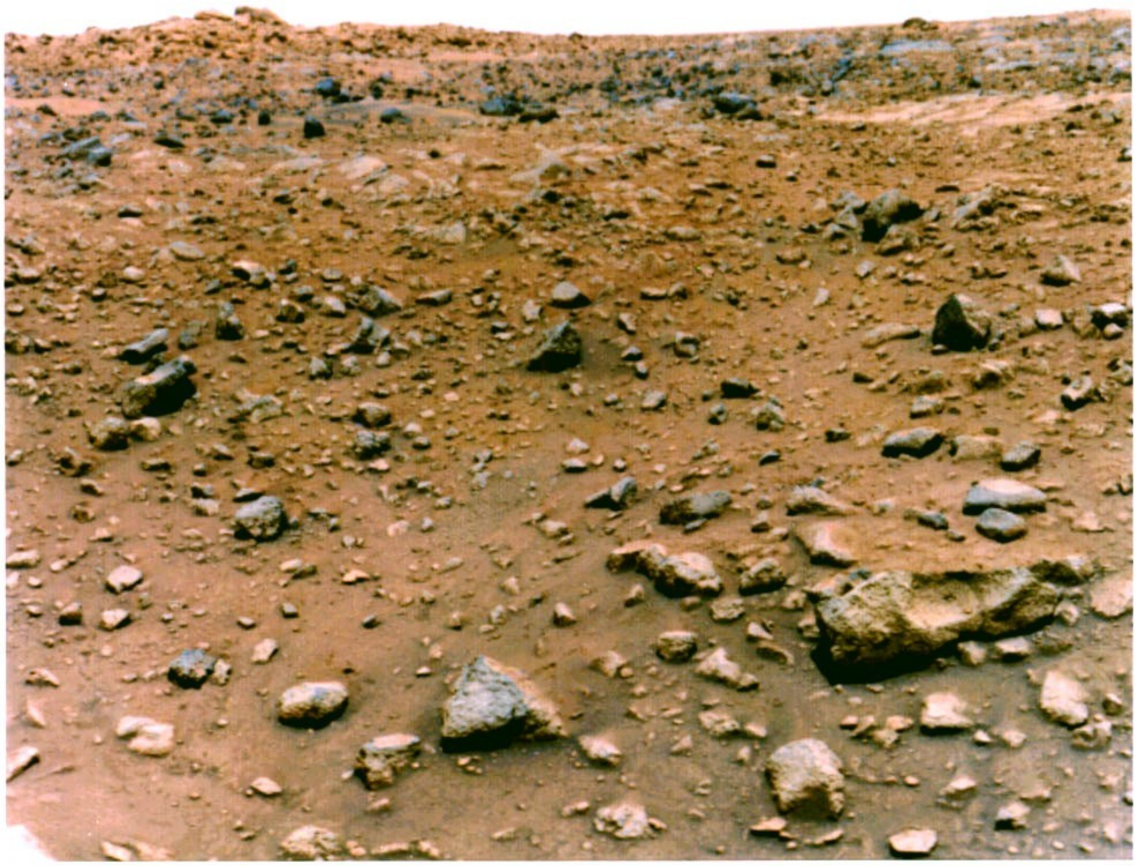

Fig. 1. Radiometric ("true color") Viking Image 12A006/001, **Viking 1 Lander Site.**

Examination of all Viking Lander images showed not only colored (ochre to yellow-to-yellow-green to green) patches on some of the foreground rocks, but seasonal changes in the colors and patterns of the same objects when viewed under the same conditions, as seen, for example, in Figures 2a and 2b.

Fig. 2a.   Fig 2b.

Fig. 2a. Radiometric color picture of Viking lander site 1, taken sol 1. Viking Picture 12A006/001; Fig. 2b. Same view (but different time of day) taken sol 302 showing changes on rocks and ground surface. Viking Picture 12Dl25/302.

Radiometric images (true color) were taken at the same time and sun angle each Mars year for three consecutive years. Even though a soil sample had been retrieved from the area between years one and two, color and pattern changes independent of detritus from the sampling are seen over the years. See Figure 3.

FIG. 3. Radiometric Images over a three-year span at Viking site 1.

Lichen are called “the pioneers of vegetation” because they are frequently the first organisms that appear on newly habitable rocks or soil, as exemplified by their early appearance on volcanically-formed island of Surtsey. Capable of surviving under severe conditions by undergoing cryptobiosis, they might survive within debris ejected from Earth to Mars by meteoric impact. Since Viking, lichen have been reported[34] to survive under simulated Martian conditions and the conditions of outer space. From time to time, lichen have been mentioned as likely candidates for life on Mars. In this context, Dr. Mike Meyer, Director of NASA’s Planetary Programs, exhibited[35] the lichen-coated rock seen in Figure 3a. Figure 3b. shows “Delta Rock” imaged at Viking lander site 1.

Fig. 4a. Lichen-Coated Rock

Fig. 4b. “Delta Rock” on Mars

As stated above, Viking’s imaging system was too coarse in its resolution to support its six-channel spectral analysis that showed a striking coincidence between the greenish spots on Martian rocks and green lichen on terrestrial rocks when viewed under the JPL Viking Imaging System. The extraordinary capabilities of the Curiosity camera systems offer an opportunity to resolve whether any such patches found by the MSL are biological or not. Biological features, such as foliose or crustose patterns, hyphae, cortex, medulla and cephalodia of lichen might readily be identified by the hi res camera and the hand lens. Alien life form on Mars might well exhibit features morphologically attributable to biology.

Visual and Chemical Proof of Life

As mentioned above, Curiosity can, in itself, completely corroborate the presence of life on Mars. Should colored patches be seen on rocks, after their close visual

inspection, these patches can be targeted by the ChemCam. The spectroscopic information obtained might support the visible evidence for life, making a "bullet-proof," or Occam-resistant case for life.

The author conveyed these concepts of the camera "stealth" life detection experiments to Dr. Michael Malin, developer and Principal Investigator of the Curiosity camera systems, together with the paper cited above that first indicated colored patches on Martian rocks. Dr. Malin said[36] he would closely examine any such spots at high resolution, but said mission operations prevented him from returning to the same locations to look for temporal changes as I had further suggested. The author believes, however, that, should SAM and ChemCam show positive evidence for life, the Curiosity Mission will direct the MSL rover back to the same spot at a date sufficient to show changes in color or pattern resulting from growth or decay. This could constitute the greatest feat imaginable for the Curiosity mission.

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