The revival of life on Mars

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ABSTRACT

Few, if any, major scientific quests have taken such frequent, diametrically opposed changes in prospect and direction as has the search for life on Mars. The erratic courses and their supporting rationales are traced: from Percival Lowell's astonishing pronouncement of intelligent beings on the red planet; to their denouement by Mariner 4; to the strong contraindications of any form of Martian life relayed by Mariners 6 and 7; to the discovery of a different, perhaps once-habitable, Mars revealed by the detailed orbital images, including the first evidence of ancient rivers, taken by Mariner 9; to the still-controversial claim of the detection of microbial life by the 1976 Viking Missions; to NASA's subsequent prohibition against any Mars life detection experiments; to the recently emerged consensus, propelled by findings of Pathfinder, the Mars Exploratory Rovers and the continuing discoveries of life in extreme environments on Earth, that past or extant life on Mars is likely. Against this background, the future Mars missions' experiments bearing on the life issue are reviewed. The case is made that none of these experiments, as currently planned, still subject to the prohibition against direct life detection experiments, can resolve this paramount and fundamental question that bears so heavily on the origin and distribution of life, and our place in the universe.

Key Words: Mars, life on Mars, search for life on Mars, astrobiology, extraterrestrial life, origin of life

1. INTRODUCTION AND BACKGROUND

On August 4, NASA's Phoenix Mission was launched to Mars. While Phoenix contains no life detection experiment, the probe's findings could constitute a watershed in the search for extraterrestrial life. The detection of organic matter on the surface of Mars by the new mission could confirm the claim[1], or, at least the likelihood, that the Viking Mission to Mars of 31 years ago found living microorganisms.

The tantalizing possibility that life may exist on celestial bodies other than Earth has intrigued thinking humans for thousands of years. In the 5th century B.C. the Greek philosopher Anaxagoras[2] espoused the panspermia concept, stating that life's seeds travel through space, infecting habitable planets with life.

Louis Pasteur performed the first direct experiment to detect extraterrestrial life in 1864[3], upon the fall of the famous Orgueil meteorite near Toulouse, France. Pasteur asceptically (he understood contamination) removed a center core from a piece of the Orgueil. He placed it in his hay-infusion broth, with which he was was the first person knowingly to culture microorganisms, and looked for visual evidence of growth. None occurred, and he concluded the meteor was sterile. (It should be noted, however, that even with today's advanced growth media, it is generally accepted that less than one percent of soil microorganisms has been cultured[4]). Nonetheless, the possibility of alien life afar gained increasing amounts of popular and scientific attention.

Following on Pasteur's effort, Hermann von Helmholtz added vigor to the theory of panspermia when, in a public lecture in 1871[5], he proposed that germs of life are spread by comets and meteorites. In 1903, Svante Arrhenius postulated his theory of radio-panspermia[6] by which bacterial spores were propelled across the reaches of space by the pressure of starlight.

In 1908, the rising cacophony over the possibility of extraterrestrial lfe reached its crescendo with the startling pronouncement[7] by one of the world's leading astronomers, Prof. Percival Lowell, that he had obtained irrefutable evidence of life on Mars. Moreover, he wrote, "…Mars at this moment is inhabited … by denizens … of an order

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whose acquaintance was worth the making," that is, with intelligent beings. Furthermore, Lowell called attention to seasonal color changes over very large areas of Mars, concluding that these were direct observations of waxing and waning vegetation. The eventual dismissal of Lowell's work as groundless was a setback for Mars fanciers. However, they soon transferred their interest to the possibility of lower forms of life on Mars, where the focus remains to this day.

In 1935, the Explorer II balloon[8], in an experiment designed to detect panspermia, reached an altitude of 72,000 feet, supposedly above the height attainable by terrestrial microorganisms propelled by any natural system. An evacuated canister was opened in the rarefied atmosphere to suck air through a filter. The canister was then sealed and parachuted to Earth. Microorganisms were recovered from the filter. However, many attributed the results to contamination when the canister hit the Earth or subsequently in handling of the sample.

In 1961, Claus and Nagy[9] produced controversial evidence of microbial fossils in a meteorite of unknown origin. Since then many similar reports of fossil evidence in chondrite meteorites have been published. Hoyle and Wickramasinghe[10] became prime advocates of panspermia. Wickramasinghe performed high altitude rocket experiments[11] to collect incoming alien life, again with controversial results. The most publicized, and most contested, evidence for microbial fossils in a meteorite was that of ALH84001 announced[12] by NASA in 1996. Hoover[13] has reviewed many of the numerous above-mentioned reports over the last half century in what is perhaps the most complete support for microbial fossils in chondrite meteorites, including much chemical and imaging data from his own examinations. Numerous discussions supporting and refuting panspermia continue to this day.

With the dawn of the Space Age, a series of missions was sent to Mars by NASA to garner information about the Red Planet. In 1976, the twin spacecraft of the Viking Mission[14] were landed on Mars with the prime objective of seeking living microbial life in the soil of the Red Planet. The Labeled Release (LR) life detection experiment[15] aboard each lander obtained positive responses at both landing sites. The positive responses were confirmed by nil responses from duplicate samples heated to kill microorganisms[16]. However, the results were discounted for a variety of reasons[17].

Possibly as a result of the controversy over the Viking results, none of the many subsequent missions to Mars has contained a life detection experiment. Even ESA's recent announcement[18], "Digging Deep for Martian Life," describing the ExoMars rover scheduled to land on Mars in 2013, reveals that, despite the title of the release (undoubtedly reflecting the public's interest), the rover, 31 years after Viking, will not actually contain a life detection experiment. Not to seek to duplicate, and expand, a highly provocative scientific result (highly provocative, be it biological or chemical) as that obtained by the Viking LR seems a strange retrogression of the scientific method so painstakingly established over the last several centuries. A modification of the LR experiment seeking chiral specificity in metabolism of labeled substrates as confirmation of the Viking LR results as evidence for life was described[19] and proposed to NASA and ESA several times, but not selected. Instead, NASA, emulated by ESA, instituted a policy of "follow the water" to select a promising area from which to procure a Mars sample for examination on Earth. Table 1 lists all Mars missions, showing some 16 launched since Viking.

In the three decades since Viking, most or all of the objections to accepting the LR results have been refuted[20]. More recently, DNA damage by cosmic radiation has been cited[21] as limiting life on Mars to depths below 7.5m. However, this conclusion is based on the Martian regolith down to that depth having constantly remained below freezing for hundreds of thousands of years or more. Yet, surface temperature measurements made by Viking, Pathfinder and MER record values of 273^{o} K to over 295^{o} K around local noon, which, in keeping with that very publication, would allow ample time for repair of radiation-damaged DNA.

A still later publication[22] proposes that the Viking LR did detect life on Mars, and uses the Viking results to propose that the life detected is based on a cytoplasm mixture of water and H_2O_2. While this article and others cited support the possibility of Martian life, only modest acceptance has evolved.

Most recently, the case for life has been advanced by an article[23] in an official scientific journal of Argentina that accepts the Martian LR results and names the species of microorganism detected "*Gillevinia straata*". The intended effect was to reverse the burden of proof concerning the life issue, but the controversy remains.

TABLE 1. Mars Mission Launch Sequence

Historic Mars Missions:

1960 October 10, A2-e (Vostok)
(Mars 1960A), also Korabl 4 or Marsnik 1 (USSR): Failed to achieve Earth orbit. Marsnik 1 (NSSDC)
1960 October 14, A2-e
(Mars 1960B), also Korabl 5 or Marsnik 2 (USSR): Failed to achieve Earth orbit. Marsnik 2 (NSSDC)
1962 October 24, A2-e
Sputnik 22, also Mars 1962A or Korabl 11 (USSR): Failed to leave Earth orbit (blew up). Sputnik 22 (NSSDC)
1962 November 1, A2-e
Mars 1, also Sputnik 23 (USSR): First probe to pass Mars (at about 190,000 km), but contact lost on March 21, 1963. Mars 1 (NSSDC)
1962 November 4, A2-e
Sputnik 24, also Mars 1962B or Korabl 13 (USSR): Failed to leave Earth orbit (blew up). Sputnik 24 (NSSDC)
1964 November 5, Atlas-Agena D
Mariner 3 (Nasa): Launched by Atlas-Agena D, Mariner 3 went into Solar orbit, but as the aerodynamic protection shroud failed to be jettisoned, it reached a wrong orbit and missed Mars by a wide margin. Mariner 3 & 4 mission page (JPL) - Mariner 3 (NSSDC)
1964 November 28, Atlas-Agena D
Mariner 4 (Nasa): First successful Mars mission. Passed the red planet at 9825 km on July 14, 1965, and returned 22 TV pictures of its surface. Discovered the cratered nature of Mars' surface. Mariner 4 image; Mariner 3 & 4 mission page (JPL); Mariner 4 (NSSDC) - Mariner 4 images catalogue - ftp access - Mariner IV - First Flyby of Mars, by Bill Momsen
1964 November 30, A2-e
Zond 2 (USSR): Passed Mars at less than 1000 miles (1500 km) on August 6, 1965, but communications was lost on May 4 or 5, 1965, so no data were returned. Zond 2 (NSSDC)
[1965 July 18], A2-e
Zond 3 (USSR): Flight to Mars orbit (not the planet). Transmitted 25 images of the lunar far side, communication from up to 31 million km Zond 3 (NSSDC)
1967 March 27, A2-e
(unnamed Mars ?) (USSR): Launch Failure
1969 February 24, Atlas-Centaur
Mariner 6 (Nasa): Successful fly-by at 2120 miles (3410 km) occurred on July 31, 1969. Returned data and 75 photos, mainly from the equatorial region. Found that most of Mars' atmosphere was made of carbon dioxide. Mariner 6 or 7 image; Mariner 6 & 7 mission page (JPL); Mariner 6 (NSSDC); Mariner 6 & 7 Image Browser - Software for Mariner 6 and 7 TV Experiment by Piotr Marek
1969 March 27, Atlas-Centaur
Mariner 7 (Nasa): Successful fly-by at 2190 miles (3524 km) on August 5, 1969; returned data and 126 photos, flying over the south polar region. Was probably struck and slightly damaged by meteor a few days before arrival. Mariner 6 or 7 image; Mariner 6 & 7 mission page (JPL); Mariner 7 (NSSDC)
1969 March 27, D1-e (Proton)
(Unnamed Mars 1969A) (USSR): Failed to achieve Earth orbit. Mars 1969A (NSSDC)
1969 April 14, D1-e
(Unnamed Mars 1969B) (USSR): Failed to achieve Earth orbit. Mars 1969B (NSSDC)
1971 May 8, Atlas-Centaur
Mariner 8, also Mariner-H (Nasa): Due to second stage failure of the launcher, fell into Atlantic. Mariner 8 & 9 mission page (JPL) - Mariner-H (NSSDC)
1971 May 10, D1-e
Cosmos 419 (USSR): Intended orbiter/lander mission, failed to leave Earth orbit. Cosmos 419 (NSSDC)
1971 May 19, D1-e
Mars 2 (USSR): The Mars 2 Orbiter reached Mars orbit of 860x15,500 miles (1380x25,000 km) successfully on November 27, 1971. The lander became the first human-made object to reach the surface of Mars when it

TABLE 1. Mars Mission Launch Sequence (continued)

crashed on the planet on the same day. Because of a global dust storm at arrival time, the orbiter could return only pictures with little surface detail. Mars 2 (NSSDC) - Mars 2 Lander (NSSDC)

1971 May 28, D1-e

Mars 3 (USSR): The Orbiter reached Mars orbit (930x124,000 miles, 1500x200,000 km) successfully on December 2, 1971. The lander achieved the first soft landing on Mars on the same day (at 45 deg S, 158 deg W, between Electris and Phaetontis regions), but failed after 110 seconds after transmitting a small portion of a picture. Together with the images returned by Mars 2, a color picture of the global dust storm of December 1971 was composed. Mars 3 (NSSDC) - Mars 3 Lander (NSSDC)

1971 May 30, Atlas-Centaur

Mariner 9 (Nasa): Successfully achieved Mars orbit of 850 x 10,650 miles (1390 x 17,140 km) to become Mars' first artificial satellite, and returned 7,329 TV pictures covering the entire surface of Mars, providing the first full photographic atlas, or photo globe, of a celestial body, until it was shut down on October 27, 1972 after 698 orbits, or 349 days in orbit (a total mission of 515 days). Discovered volcanoes, flow channels, and more surface structures. Mariner 9 image: 21k jpg, 279k jpg; Mariner 8 & 9 mission page (JPL); Mariner 9 stuff (NSSDC); Mariner 9 image browser (Peter Masek)

1973 July 21, D1-e

Mars 4 (USSR): Intended Mars orbiter; arrived at Mars on February 10, 1974, but failed to get inserted in Mars orbit, and passed by the planet at 2240 km.

1973 July 25, D1-e

Mars 5 (USSR): Reached Mars orbit on February 12, 1974, but failed 10 days after orbit insertion, after returning some photos. Mars 5 (NSSDC)

1973 August 5, D1-e

Mars 6 (USSR): Lander spacecraft; crashed on Mars on March 12, 1974. Mars 6 (NSSDC)

1973 August 9, D1-e

Mars 7 (USSR): Intended lander, missed Mars by 1280 km on March 9, 1974. Mars 7 (NSSDC)

1975 August 20, Titan IIIe - Centaur - TE 364-4

Viking 1 (Nasa): Orbiter and lander mission (a Viking craft is shown in our image; the lander is sitting above the orbiter, packed in the protection cover). The spacecraft reached Mars orbit on June 19, 1976, the lander softlanded on Mars on July 20, 1976, in Chryse Planitia at 22.48 d North areographic latitude, 48.01 d Western longitude. Both orbiter and lander performed extremely successful missions, but the lander's bio experiments returned ambiguous results concerning microbiotic life on Mars. Viking Orbiter 1 was successfully working until August 7, 1980, when it went out of altitude control propellant, Viking Lander 1 until November 13, 1982 when it was accidentally shut down. Viking 1 Orbiter - Viking 1 Lander (NSSDC)

1975 September 5, Titan IIIe - Centaur - TE 364-4

Viking 2 (Nasa): Orbiter and lander mission. Reached Mars orbit on August 7, 1976, lander softlanded on September 3, 1976, in Utopia Planitia 47.97 d N, 225.74 d W, 7,420 km North-East of Viking 1. Both Viking 2 orbiter and lander were equally successful as the sister craft Viking 1; Viking Orbiter 2 was active until July 25, 1978, when its altitude control propellant had been used up, Viking Lander 2 returned data up to August 7, 1980, when Viking Orbiter 1 was shut down, which had been served as communications relay.
Viking 2 Orbiter - Viking 2 Lander (NSSDC)

Both Viking missions were extremely fruitful in both the quality and the quantity of acquired data: The orbiters collected some 52,000 images and cartographed 97 per cent of the Martian surface from orbit, often from different angles so that the topography could be determined. The landers returned some 4,500 photos and weather data from the Martian surface, documenting seasonal changes, besides the well-known soil investigations and bio experiments. Viking spacecraft image (inflight configuration with orbiter and lander; shown in this page); Viking info, images and links at SEDS; Viking homepage at Nasa's NSSDC; Viking homepage at NASM; Viking 1&2 (JPL)

1988 July 5, D1-e

Phobos 1 (USSR): Intended to investigate Mars' moon Phobos, this craft lost contact midway on September 2, 1988 because of an erroneous control command sequence. Phobos Homepage; Phobos image [29k jpg]; Phobos Project Information (NSSDC)

TABLE 1. Mars Mission Launch Sequence (continued)

1988 July 12, D1-e
Phobos 2 (USSR): Successfully reached Mars orbit on January 29, 1989, and returned data and photos of Mars and Phobos. During an approaching maneuver to Phobos, the craft lost orientation due to computer defect, and suffered energy loss, which terminated the mission. Phobos Homepage; Phobos image [29k jpg]; Phobos Project Information (NSSDC)
1992 September 25, Titan IIIe-TOS
Mars Observer (Nasa): Reached Mars on August 21, 1993, and sent some TV images on approach. Contact was lost during its orbit insertion ignition; it may have been damaged, blown up, or simply frozen after having lost orientation.
Mars Observer spacecraft image [22k gif, caption]; Mars Observer images at SEDS; Mars Observer Images from its interplanetary cruise at Malin Space Science Systems; Mars Observer page at HEASARC (GSFC/Nasa); Mars Observer (NSSDC) Mars Observer (JPL)
1996 November 7, Delta II, currently operating in Mars orbit.
Mars Global Surveyor (Nasa): Mars orbiter, launched from KSC, Cape Canaveral. Reached Mars and successfully entered Mars orbit on September 11, 1997. Uses aerobraking for achieving the low Mars orbit required for the intended orbital investigations of the Red Planet, which began in early 1998. Since, the spacecraft is still providing numerous high-resolution images and valuable data of the Martian surface and atmosphere. MGS spacecraft image [141k gif]; MGS info, images and links at SEDS; MGS Homepage; MGS info (NSSDC)
1996 November 16, D1-e
Mars 96 (Russia): intended Mars orbiter with 4 landers and 2 penetrators; experiments from 22 countries. Failed to leave Earth orbit, and decayed soon after liftoff. Mars 96 homepage; Mars 96 (NSSDC)
1996 December 4, Delta II
Mars Pathfinder (Nasa); renamed Carl Sagan Memorial Station after landing: Mars lander with Sojourner rover. Launched from KSC, Cape Canaveral; softlanded on Mars on July 4, 1997, in direct approach, in Ares Valley, at 19.5 d N, 32.8 d W. Sojourner was released to the Martian surface on July 6, and performed investigations of Martian soil and rocks around MPF. Both spacecraft operated extremely successful until the last data transmission on September 27, 1997, and after a last signal received on October 7, 1997, contact was lost, perhaps because of battery failure partially due to falling temperatures at the landing site. MPF image; Sojourner image; MPF info, images and links at SEDS; Mars Pathfinder Mission Page (JPL); Mars Pathfinder homepage; MPF info (NSSDC)
1998 July 4, M-V
Nozomi (Hope), formerly Planet-B (Japan). Intended orbiter to study Mars' upper atmosphere. After two Lunar and one Earth swingby maneuvers, the craft was originally scheduled to arrive at Mars on October 11, 1999. Unfortunately, due to a problem with its propulsion system, the spacecraft got "insufficient acceleration." A new orbit was calculated, and after two more Earth swingbys and a delay of more than 4 years, arrived in the neighborhood of Mars with a re-scheduled orbital insertion on December 14, 2003. Unfortunately, a correction maneuver on December 9, 2003 failed so that the mission had to be abandoned; after a flyby of Mars at 860 km on December 14, 2003, Nozomi remains in an interplanetary Solar orbit. Planet-B image [158k gif]; Nozomi information, images and links from SEDS; Nozomi (NSSDC)
1998 December 10, Delta II
Mars Climate Orbiter (Nasa), former Mars Surveyor 1998 Orbiter. Was to study Martian weather and climate. Contact to spacecraft lost when it disappeared behind planet Mars for Mars Orbit Insertion on September 23, 1999. The spacecraft was probably destroyed in Mars' atmosphere when it came too close to the planet due to a navigation error. Mars Climate Orbiter image [5k jpg]; MCO information, images and links at SEDS; MCO homepage and Mars Climate Orbiter Mission page (JPL); MCO info (NSSDC)
1999 January 3, Delta II
Mars Polar Lander (Nasa), former Mars Surveyor 1998 Lander. Was to study soil and meteorology near South Polar region, and carried two soil penetrator microprobes (Deep Space 2). After a successful launch and interplanetary cruise, the spacecraft was approaching planet Mars with all systems apparently up and well, but after reaching the surface of Mars, contact was never re-established. While the reason of this loss is not known, the most probable cause is that due to a programming fault, the craft turned off its rocket engines early and

TABLE 1. Mars Mission Launch Sequence (concluded)

consequently crashed upon Mars' surface. The two microprobes, anyway hi-risk missions, also got lost due to unknown reasons. Mars Polar Lander image [25k jpg]; MCO information, images and links at SEDS; MPL, DS 2 and Mars Surveyor 98 homepage (JPL); Mars Polar Lander/Deepspace 2 Mission Page (JPL); MPL and DS2 info (NSSDC)

2001 April 7, Delta II, currently operating in Mars orbit.

2001 Mars Odyssey, Mars Surveyor 2001 Orbiter (Nasa). Mars orbiter. After an over 6 month interplanetary cruise, the spacecraft arrived at Mars and was successfully inserted into Mars orbit on October 24, 2001 (UT; see Mars Orbit Insertion (MOI) information). This mission is to perform the research originally scheduled for the lost Mars Climate Orbiter (Mars Surveyor 1998 Orbiter), i.e., Mars weather and climate. It is also intended to test aerocapture techniques, study Mars from orbit, serve as communications relay for future landers. 2001 Mars Odyssey information, images and links at SEDS; 2001 Mars Odyssey homepage (JPL); 2001 Mars Odyssey info (NSSDC)

2003 June 2, Soyuz-Fregat, currently operating in Mars orbit. Beagle-2 lander lost on Mars' surface.

Mars Express (ESA), Orbiter and Lander. Mars Express orbiter was successfully inserted into the Martian orbit on December 25, 2003. The Beagle 2 lander was successfully separated on December 19, and reached Mars in direct approach on December 25, 2003. Unfortunately, the lander could not be contacted after landing, and is lost in the region Isidis Planitia. The Mars Express orbiter started its scientific mission and is busily taking photographs and data from its orbit around Mars. Mars Express information, images and links at SEDS, Mars Express homepage (ESA); Beagle 2 lander homepage (Open University); Mars Express info (NSSDC)

2003 June 10, Delta 2 (7425), currently operating on the surface of Mars.

Spirit, 2003 Mars Exploration Rover 2, MER-2, MER-A, Mars Surveyor 2003 Lander/Rover A (Nasa). First of two sister spacecraft (the other is Mars Exploration Rover B, Opportunity). A large (~130 kg) rover based on the Athena Rover concept, to land using an airbag system, without stationary lander. Successful softlanding occurred on January 4, 2004, 4:35 UT (January 3, 8:35 p.m. PST) in Gusev crater on Mars. The lander is currently investigating the landing site region, intended for at least 90 days. 2003 MER information, images and links at SEDS, Mars Rovers Home - 2003 Mars Exploration Rovers Homepage (JPL), Spirit, Mars Exploration Rover A (MER-A) info (NSSDC), Twin Rover Press Release (Nasa HQ PR 00-124, August 10, 2000); Mars 2003 and 2005 page (NSSDC)

2003 July 7, Delta 2 (7425), currently operating on the surface of Mars.

Opportunity, 2003 Mars Exploration Rover 1, MER-1, MER-B, Mars Surveyor 2003 Lander/Rover B (Nasa). Second of two sister spacecraft (the other is Mars Exploration Rover A, Spirit). A large (~130 kg) rover based on the Athena Rover concept, to land using an airbag system, without stationary lander. Successful softlanding occurred on January 25, 2004, 5:05 UT (January 24, 9:05 p.m. PST) in the Meridiani Terra region on Mars. Operations, scheduled to last for a nominal 90 days, greatly exceeded that mark, with some activities still under way. MER information and images at SEDS, Mars Rovers Home - 2003 Mars Exploration Rovers Homepage (JPL), Opportunity, Mars Exploration Rover B (MER-B) info (NSSDC), Twin Rover Press Release (Nasa HQ PR 00-124, August 10, 2000); Mars 2003 and 2005 page (NSSDC)

2005 August 12, Atlas V

Mars Reconnaissance Orbiter, Mars Surveyor 2005 Orbiter (Nasa). Arrived at Mars on March 10, 2006, inserted into highly-eccentric orbit; To study Mars from orbit between November 2006 and November 2008, perform high-resolution measurements including images with a resolution of 20 to 30 cm, and possibly serve as communications relay for later Mars landers until about 2010. 2005 MRO information, images and links at SEDS, Mars Reconnaissance Orbiter homepage (JPL), Mars 2003 and 2005 page (NSSDC)

2007 August 4, Delta

Phoenix - Small Scout Mission (Nasa): An in-situ volatile and organic molecule survey (LPL/Univ of Arizona). Lander designed to land within Martian Arctic Circle, and obtain ice and soil samples for onboard detailed chemical analyses. To arrive at Mars on May 25, 2008. Phoenix information, images and links from SEDS; Phoenix homepage (LPL, University of Arizona); Phoenix info (JPL).

Credit: SEDS Mars Link and Exploration page: http://seds.org/~spider/mars/mars-l.html with some edits by GVL.

It is interesting to compare and analyze the controversy that followed Percival Lowell's pronouncement of intelligent life on Mars to that persisting through the three decades since Viking's LR data were obtained. An examination of Lowell's book[24] shows that, for the most part, he carried out a meticulous and accurate mathematic analysis of his data. The problem was that his key data were faulty. They were obtained from instruments (Schiaparelli's and Lowell's telescopes) inadquate to the task. When optical resolution failed at the sensitivity required to detect the "canals" in photographs, Schiaparelli in his map of 1877 and, subsequently Lowell, augmented it with their own vision. However, one of the mysterious qualities of human vision is its ability to connect dots, to yield real or imaginary lines otherwise too fine for resolution. Among the advances contributed by Lowell's work are: the determination that Mars is a desert; his use of "slant illumination" to determine (incorrectly because of his inadequate telescope) peaks and valleys, recognition of water and CHNOPS as essential components of life; Mars' lack of a significant iron core, projected from extreme habitats on Earth to life "modifications" that were possible on other planets; determination of water ice as the Martian polar cap as opposed to frozen CO_2; that the temperature of the surface of Mars could permit life; a learned discussion of planetary geology, climatology and evolution, including a rationale for Mars having cooled sooner than Earth; and the very significant detection of water vapor on Mars. However, the quality of the analysis falters in the later stages of the book. Although a number of telescopic photographs illustrate the text, and the statement is made that photographs do show the "irrigation ditches" on Mars, none is reproduced in the book. Only Lowell's drawings of this critical observation are presented.

With respect to the Mars LR data, the very opposite pertains. The LR data were digital, and in complete, statistically significant detail. There was no problem of resolution or ambiguity, and no extrasensory perception was required or used. Separate active experiments confirmed each other, as did the separate programmed and improvised controls. The author's constant review of the literature has, to this date, found no publication casting any doubt on the performance of the experiment, or on the validity of the data obtained. Nor has anyone communicated such to him. It is the interpretations of the accepted data that differ. The conclusion that life was the active agent is based on the satisfaction of the pre-mission criteria for the detection of life, as amplified by the improvised, ad hoc experiments conducted on Mars, supplemented and supported by new findings on Mars and Earth that bear on the life issue. The pro-life case was based on deductive reasoning from the direct data and on inductive reasoning based on the new knowledge of life potentials on the two planets. These two rationales not only concurred, but dove-tailed with no awkward omissions or superfluous parts. On the other hand, the supporters of an abiological agent have failed to identify a specific chemical or physical phenomenon that could account for the results. Those candidates proferred have failed both theoretical and experimental scrutiny. Absent a demonstrated, specific agent, they have proposed barriers to the existence of life on Mars. One by one, these barriers have fallen to the new knowledge gained about the Martian environment and the recognition of the biologic imperative on Earth, as demonstrated by the finding of thriving ecosystems in extreme environments previously believed inimical to life. These include environments comparable to those at the Viking landing sites. All of the foregoing is documented in the references already cited. Nonetheless, the "consensus," although in recent years showing some tendency to change, remains in the abiological camp. Thus, in the case of the Mars LR experiment, it is the analysis of "bullet-proof" data that seems at fault, not, as in Lowell's case, the data upon which his analysis was based. Perhaps this strange juxtiposition in these modern times is caused by society's reluctance, at all levels, to accept a major paradigm change.

2. STATUS

The status of the issue of life on Mars may be briefly summarized. Despite all the knowledge now in hand, the spectrum of "informed" opinions covers a very broad spectrum with strongly bi-polar ends, one populated by those stating that the conditions on Mars make life impossible, and those at the other end accepting life on Mars as proven fact. These are both minority groups, although a shift in life's direction is evident. In a poll taken of attendees at the ESA anniversary meeting in the Netherlands[25], 75% said they believed life on Mars was possible. Of those, 25% said they believed it is present there today.

The spectrum of opinions ranging progressively from a sterile Mars to a living planet includes:

1. Mars never could have supported life because of lack of liquid water[26;27];
2. The LR response on Mars was caused by chemical[28] or physical[29] agents, a strong oxidant or UV-induced defects in minerals;
3. Liquid water present in the remote past could have supported life, but the water is gone and life is now extinct[30];

4. Underground oases of liquid water might support life now[31], as opposed to life's omnipresence on Earth;
5. Viable microorganisms, as on Earth, might be found in underground permafrost[32,33,34];
6. Life may exist in caves on Mars[35];
7. Sufficient liquid water is present on the surface of Mars today to support microorganisms (such as produced the positive Viking LR responses)[36,37];
8. The sustained preponderance of UV-labile CO_2 over its photolysis product, CO, in the Martian atmosphere constitutes the type of disequilibrium proposed[38] as indicative of life.;
9. Various macro-features on Mars, such as variable colored spots on rocks with the spectral response of lichen[39], and the seasonal development of large dark circular patches on polar ice fields[40] are indicative of extant life;
10. The redness of the soil of Mars may be indicative of life[41];
11. Current life was detected by Viking[42,43] ;
12. A circadian rhythm in the Mars LR data is evidence for biology[44,45,46];
13. Methane detected in the Martian atmosphere in amounts unsupportable by volcanism is evidence for life[47,48,49,50,51]; with which the detections of formaldehyde and, possibly ammonia are consistent.
14. The Viking LR detected life, but that life is based on a solvent combination of liquid water and hydrogen peroxide[52]
15. Life may exist based on solvents other than liquid water[53,54,55];
16. The redness of the Martian soil may have resulted from microbial processing[56]
17. Various mutually compatible combinations of the foregoing.

3. FUTURE MISSIONS TO MARS

Future missions that had been planned for Mars are shown in Table 2. However, in response to present and anticipated budget cuts, NASA's planetary program is in a state of revision. Many planned missions may be postponed or cancelled. It had been planned that a Mars mission with a human crew would be launched in 2018 (to arrive at Mars in 2019) to begin an era of permanent human presence. This schedule is now highly doubtful.

As in all missions other than Viking, none contains a life detection experiment. However, as mentioned in the opening statement, the Phoenix Mission[57] has great portent for solving this age-old mystery. Were it to find organic matter in the top soil of Mars, this would remove the major impediment to acceptance of the Viking LR results as evidence for living organisms, and would likely swing the consensus to that conclusion. Without such a finding, the next possibility would lie with the planned missions to bring a Martian sample to Earth for laboratory examination for living or dead life forms. However, the difficulty of providing and maintaining life support over the months of transit from Mars to Earth remains to be solved. Providing for still unknown environmental and nutritional requirements is daunting. Should dead life forms be found in a sample, it would be difficult to conclude that those organisms were alive when obtained.

A variety of increasingly sensitive instruments[58,59] to detect and analyze organic matter is stressed in the future missions. Phoenix will seek to land within the Arctic Circle where the investigators believe the likelihood of liquid water is greater than at mid latitudes. Phoenix will examine soil and subsurface ice in its analyses. Deep drills have been advocated for future missions[60] to sample various depths beneath the surface where, some believe, liquid water may be found and where microorganisms might survive cosmic radiation. It has also been proposed[61] to examine ice in Martian craters, such as Elysium, for evidence of life.

An examination of past and future Mars missions leads to the question of whether the traditional scientific method of investigation has been utilized. That method devises tools for inquiry. When a tool achieves interesting results, confirmation of the results is sought in a duplicate experiment. Should the results be confirmed, the tool that opened the wedge is then refined to gain additional information. This elementary scientific procedure was not followed in the life-oriented exploration of Mars. No doubts have been cast on the response obtained by the Viking LR experiment on Mars. It is the interpretation of those results that is the issue. Whether the results were caused by biological or chemical agents, the fact that the surface of Mars is so highly reactive to the LR nutrient solution is of major scientific significance, warranting continued investigation. Yet, no further use has been made of the LR technique. This despite the development of a modification that could remove any ambiguity from the response by dosing Martian soil with separate chiral isomers of optically active compounds. Any response showing chiral preference would be a sure sign of on-going metabolism. Recommended[62] and proposed[63] many times, the method has been ignored by NASA and ESA. Instead, the life detection approach was changed to one of "follow the water." Even this approach, however, is puzzling.

TABLE 2. Missions Scheduled for the Future

2009 December
Mars Science Laboratory, Mars Smart Lander, Mars 2009 Mobile Scientific Laboratory (Nasa): Formerly scheduled for 2007, the spacecraft is now to be launched in December 2007, and to arrive at Mars in October 2010. Will include new technologies: A small long-range, long-duration rover powered by a small nuclear reactor, equipped to perform many scientific studies of Mars, and to demonstrate the technology for accurate landing and hazard avoidance in order to travel to difficult-to-reach sites. 2009 Mars Science Laboratory information, images and links from SEDS; 2009 MSL page (JPL), Smart Lander page (JPL), Mars 2003 and 2005 page (NSSDC)
2009 Late
Phobos-Grunt (Russia). Scheduled sample return mission to Martian moon Phobos.
2009 Late
Beagle 2: Evolution (ESA). Mars Lander.
2011
Mars Scout 2 (Nasa). A mission succeeding and extending the 2007 Mars Scout, Phoenix; details to be defined. Mars Beyond 2009 page (JPL); Mars 2003 and 2005 page (NSSDC)
2011
Exo Mars (ESA). Will include an orbiter and a descent module that will land a highly mobile rover, weighing up to 200 kilogrammes, on the surface of Mars.
2014
Mars 2014 (Nasa; possible participations from France and Italy) Possibly first sample return mission. Mars Beyond 2009 page (JPL); Mars 2003 and 2005 page (NSSDC)
2016
Mars 2016 (Nasa, international?; under study). Possibly another sample return mission, or orbiters, landers, rovers. May include a Mars Astrobiology Field Laboratory, or Deep Drilling or other technologies. Mars Beyond 2009 page (JPL); Mars 2003 and 2005 page (NSSDC)

Credit: SEDS Mars Link and Exploration page, http://seds.org/~spider/mars/mars-l.html with some edits by GVL.

While instruments sent to Mars have detected hydrogen[64], which is proposed to be part of the water molecule, no experiment has been sent capable of detecting water in liquid form, which is key to NASA's search for extant life. A summary of the status of the search for life on Mars is that the active, direct search is no further advanced than it was after the Viking LR returned its positive response in 1976. However, important new knowledge bearing on the issue has been obtained from Mars: Pathfinder found[65] that mid-day atmospheric temperatures at the Mars surface surpass 20^o C; Odyssey[66] measured several soil-percent of a hydrogen compound (presumbaby water) at both Viking landing sites, and within several centimeters of the surface over much of the planet; the water in the Mars atmosphere is concentrated largely just above the surface, providing a water-vapor-saturated atmosphere, which, together with the often imaged presence of ice[67], provides the conditions for liquid water in the surface material; methane has been detected in the lower Martian atmosphere, in association with water vapor, and in amounts requiring constant replacement, suggestive of a biological source[68]; formaldehyde and, possibly, ammonia have also been reported[69], all of which are supportive or consistent with the presence of extant life. Equally import has been the finding of life in domains on Earth previously thought uninhabitable, in effect establishing a biologic imperative on this planet, with life occupying every niche tested for it (in the seas, beneath the seas, beneath the land, on the surface of the land, and in the clouds and atmosphere, and at pHs ranging from 0.1 to 12 and temperatures from constantly below freezing to >120^o C). Together with the now acknowledged cross-contamination of Earth and Mars[70], it now seems unlikely that microorganisms from, at least, Earth have not reached Mars in viable form, where some might have found habitable beachheads from which to adapt and evolve. All of this lends strong impetus to the argument for extant life on Mars. To some extent, this is accomodated in a recent National Academy report[71] on the improved prospects for life on Mars. However, the life detection experiment proposed is the examination on Earth of a soil sample from Mars. Should acceptance grow for the biological interpretation of the Mars LR experiment, this will become an unlikely scenario out of appreciation for the risk to Earth that importing a sample from Mars might entail.

4. BEYOND MARS

When the consensus prevailed that Mars was sterile, the newly developing science of astrobiology expanded its reach to look for what many felt were more promising targets for life. These include any extraterrestrial objects where liquid water is suspected, such as Titan, Europa, Ganymede, Callisto and Io[72], other moons, planets and, more recently, comets, and asteroids[73]. Also very recently, the requirement for liquid water as essential for life has been challenged[74], and alternate vital solvents and biochemistries envisioned. Some efforts are being devoted to planning or, at least, conjecturing about appropriate missions[75].

5. ORIGIN

The ultimate questions that underlie all the astrobiologcal efforts are “How did life originate, and where?” Planetary missions, even if successful in detecting life, are likely merely to regress these questions rather than to answer them. For instance, should it be shown that the chirality of Martian life is different from that of terrestrrial life, this would, at best, demonstrate independent origins of life, but will likely provide little additional clues as to the mechanisms or locales of those origins. Several approaches to solve the ultimate problem of biological origin have been made. The ancients, and moderns up into the nineteenth century, performed experiments by allowing organic matter to rot and “generate” living entities. However, the invariably positive results did not explain exactly how the material became alive. Pasteur showed the fallacy of this approach by demonstrating that sterile organic matter does not produce life; stating that only life begets life, a maxim that remains unbroken to this day. A watershed in the quest to explain life was thought to have been achieved when organic compounds were evoked from mixtures of “primative Earth atmosphere” subjected to electric discharge[76]. It was theorized that life might have started in this manner in ponds of water in which the organic molecules formed and interacted[77]. Modern laboratory techniques have attempted to generate living cells or precursers to living cells from such compounds or similar ones[78]. The work produced rudimentary bubbles of condensed organic material, with claims being made that these “proteinoids” resembled cell walls (however, devoid of anything resembling cytoplasm) and demonstrated replication, but no metabolism was achieved. A theory[79] that life on Earth did not originate in surface waters, but deep underground in very warm regions or in the deep sea thermal vents has been gaining converts. The possibility that life, or its precursors, originated on comets has also come into increasing consideration[80,81] with the finding of organic volatiles and water in comets. Next month, September, the launch of NASA’s Dawn spacecraft is scheduled. Its mission is to study two asteroids, Ceres, believed to have a thick layer of water and ice, and Vesta, a volcanic body with an metal core, in order to study possible mechanisms in Earth’s formation and development, hopefully bearing on the issue of the origin of life..

The discovery of DNA and the applications of genome mapping have made possible much more sophisticated attempts to generate life *de novo*[82]. Exquisite techniques to manipulate and transfer cellular components have produced “new organisms.” However, these techniques require starting with living cells, transferring the contents of one into another to create new characteristerics, not actually creating life from non-life. However, even as we seek our origin in this “tiny corner of an obscure spiral arm of the Milky Way,” we have just learned that this assignment of our residence is incorrect. It has now been learned[83] that Earth is not native to the Milky Way, but lies within a hitherto unidentified and separate galaxy now in the process of colliding with, and being absorbed by, the Milky Way. Eventually, this will all lead to an unpleasant end to human and post-human evolution in the blinding ineluctable flash of the resulting supernova. Thus, while our fate has become remarkably clear, the Holy Grail of devining how we got here remains elusive.

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