Life Sciences in Space Research 7 (2015) A1–A5

Contents lists available at ScienceDirect

Life Sciences in Space Research

www.elsevier.com/locate/lssr

Editorial commentary

Mars water discoveries – implications for finding ancient and current life

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There is some wonderful synchronicity right now for those interested in the search for water and life on Mars. Foremost is the recent announcement by NASA and the publication of a study using spectral imaging which definitively proves that there is seasonal, flowing briny water at a number of locations on Mars (see Fig. 1) (Ojha et al., 2015). This caps some 15 years of accumulating evidence that what was previously considered impossible is actually occurring on the Red Planet. "Water is essential to life as we know it," write Lujendra Ojha, Mary Beth Wilhelm, and their co-authors. "The presence of liquid water on Mars today has astrobiological, geologic, and hydrologic implications and may affect future human exploration".[1]

This discovery comes almost simultaneously with the release of a popular movie that may boost public interest and hopefully funding for further Mars exploration, sample return missions and eventual human landings and exploration. The book and movie will also give more visibility to the importance of developing space agricultural systems and bioregenerative recycling closed ecological that are expected to be essential to sustaining exploration teams and eventual Mars settlements. At the present time research in these fields has relatively low priority for funding and lacks ambitious scope.

In recent years, public interest has also been piqued by several non-government groups, of greater or lesser credibility, proposing private ventures for human exploration of and habitation on Mars. The evidence of past and present water by a new generation of sophisticated orbiters and surface rovers is good news indeed for human missions which will likely depend on utilization of in situ resources. It is further evidence that Mars once could have supported—and may even still support—microbial life.

Fortuitously, this issue of *Life Sciences in Space Research* includes a paper on "Water Extraction on Mars for an Expanding Human Colony" by Matthew Ralphs and his co-authors (Ralphs et al., 2015). They examine water needs for inhabitants on the planet and propose several mechanisms which can accomplish water extraction from site specific locations. At high and low latitudes, icy soils and permafrost are the candidate water sources, while at the equator water extraction will need to be accomplished from hydrated minerals which contain most of the recoverable water. It is estimated that equatorial Mars soils contain between 2% and 13% water (Feldman et al., 2004; Muscatello and Santiago-Maldonado, 2012). The methods the paper discusses include drilling into subsurface frozen water and using convective heat energy or microwave energy for water extraction. In locations with icy soils another approach is building a heated structure (dome or greenhouse) to evaporate soil and subsoil moisture and collecting the water condensation (Mungas et al., 2006).

At this exciting time in Mars exploration we offer here a short review and trace some key stages and findings which have radically transformed our view of Mars. In the 19th century Percival Lowell with his imagined canals posited the planet as a dying one, drying out, with increasingly desperate inhabitants and imperiled vegetation. While these notions were soon discarded, the images from Mariner 4, the first by a spacecraft of another planet in our solar system, in 1965 seemed to corroborate a dry, cold and desolate planet with its impact craters dominating the surface, implying a very static environment. It confirmed that Mars had lost its magnetic field, had extremely low atmospheric pressure and very cold conditions. In sum, Mariner 4's data seemed to preclude the possibility of water being important on Mars except at the Martian poles which were thought to contain CO_2 and ice (Leighton et al., 1965).

The emergence of a radically different view of Mars was catalyzed by Mariner 9 in 1971 and the Viking orbiters and landers of the mid 1970s. Their images taken from lower orbit and with higher resolution instruments showed a planet which had experienced massive floods carving numerous large river valleys and terrain with eroded grooves. Dendritic systems of streams in the southern hemisphere suggested there was rain in Mars' early history (Baird et al., 1976). The new planetary surface images indicated some floods traveled thousands of kilometers and craters showing evidence of mud flows after impact. In some Martian regions there was so-called "chaotic terrain" which researchers surmised were caused by enormous, sudden losses of water carving huge channels downstream or by underground volcanism melting frozen ice causing ground collapse. Estimates for channel flow in early Mars history were as high as ten thousand times greater than that of the Mississippi River (Morton, 2002). The Viking landers added to the evidence of the role of water in Mars' past and present. Mars soils when heated showed the presence of water and soil chemical analyses showed the presence of clays, sulfates,

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[1] http://www.theatlantic.com/science/archive/2015/09/water-is-flowing-on-mars/407662/.

http://dx.doi.org/10.1016/j.lssr.2015.10.006

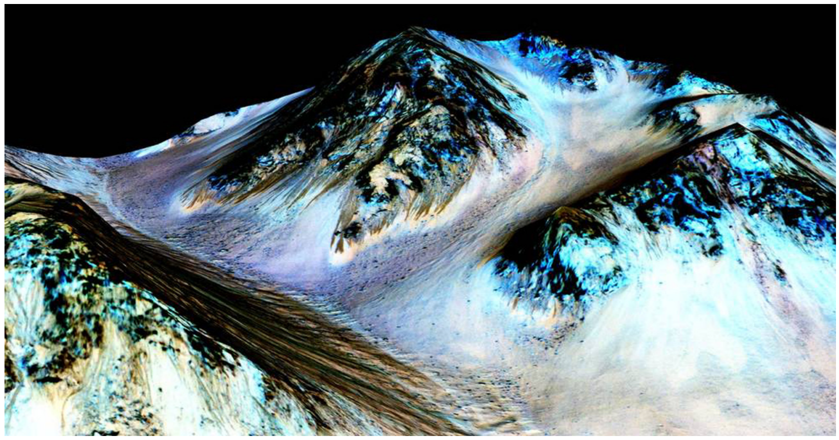

Fig. 1. An image of the 100 m dark streaks called "recurring slope lineae" which has recently been shown to be caused by water with hydrated salts flowing seasonally on the Mars surface. This confirms earlier observations and the hypothesis that there is liquid water currently on the planet (photo credit: NASA/JPL/University of Arizona).

carbonates and iron oxides all associated with exposure to water (Arvidson et al., 1989; Clark et al., 1976).

From 1996 to 2013, NASA termed the thrust of its Mars exploration science program "Follow the water." Water was seen as key to understanding Mars geological past and evolution and also as a crucial element, almost a prerequisite, allowing the possibility of life. This was the focus of the Mars Global Surveyor, the 2001 Mars Odyssey, Mars Exploration Rovers, Mars Reconnaissance Orbiter and the Mars Phoenix Lander. The success and findings of these missions along with other missions such as the European Space Agency's OMEGA/Mars Express have prompted NASA to change its focus since 2014 to "Seek the Signs of Life".[2]

Some milestones in this more recent phase of Mars exploration include identifying 60+ meteorites which originated on the planet, many showing evidence of being formed in wet environments, e.g. Hamiliton et al. (1997). River valleys, first seen by Mariner 9, have multiplied by four through higher-resolution imaging spacecraft and now are estimated at over 40,000. The same study also added to the evidence that prior to 3 billion years ago Mars had an ocean covering 1/3 to 3/4 of the planet. Some have proposed there might have been two oceans, a higher latitude one dating to 3.8 billion years associated with river valley networks and a younger and lower one, correlated with outflow channels (Carr, 2007). The ocean hypothesis still has its critics who dispute the reading of "ancient shorelines" (Carr and Head, 2003). The discovery of deltas all around Mars but concentrated in northern latitudes where it is believed Mars once had an ocean gives support to the ocean hypothesis since deltas indicate the presence of very large amounts of water (Di Achille and Hynek, 2010). The OMEGA/Mars Express mission provided data helping to delineate that there were two periods in early Mars history, one where phyllosillicates were formed by water interactions and sulfates were formed in a second era marked by an acidic environment. Later the planet dried out, losing considerable fractions of its water and almost all its atmosphere (Bibring et al., 2006). It has taken the past decade and a half of Mars exploration to begin to delineate how water-rich, albeit mostly underground, a planet Mars remains.

Lake basins have been discovered on Mars and it is believed that many craters had lakes in early Mars history (Cabrol and Grin, 2010; Matsubara et al., 2011). In 2012, direct evidence for an ancient stream in the form of water-rounded stones was found by the Curiosity rover in Gale Crater (Williams et al., 2013) giving indisputable evidence to what had been surmised from orbiting spacecraft images. Further support to the emerging consensus that Mars has abundant water resources came from the Mars Odyssey's neutron and gamma ray spectrometers which by measuring hydrogen showed that ice is plentiful and widespread on modern Mars. Below 60 degrees latitude, large regional patches show 18% subsurface ice; from 70 degrees to the poles ice increases from 25% to nearly 100% at the poles (Feldman et al., 2004).

The neutron spectrometer on the Mars Odyssey produced data that indicated if all Mars top meter of soil ice were melted and spread, it would be 14 cm deep, indicating a global average of 14% water. With the poles included, these researchers calculated a depth of water in early Mars history of 500 m over the entire planet (Feldman et al., 2004). Currently, because of loss of water due to loss of the planet's magnetic field and then atmosphere, recent estimates have calculated that if all Mars near surface ice melted it could cover the planet to a depth of around 35 m (Christensen, 2006). These calculations are constrained by the limits of current sensors which can only penetrate 1 m below the Martian surface. If all holes in the soil at deeper levels are found to be water-filled, some estimate that if melted Mars could be covered by water to a depth of a half km to 1.5 km (Boynton et al., 2002).

Other notable observations were the discovery by the Mars Express of a persistent ice lake in a polar crater and the first direct observation of ice from the surface at the landing site of the Phoenix lander. Snow and fog have also been observed. Observations from the Mars Odyssey's gamma ray spectrometer and direct measurements by the Phoenix corroborated that the polygonal shapes and troughs are caused by Martian permafrost, ground ice (Lefort et al., 2010) and the lander also found ice a few centimeters below the surface, extending to at least 20 cm deep (Arvidson et al., 2008). The Mars Reconnaissance Orbiter showed in 2008 that debris aprons even at mid latitudes are glaciers shallowly covered with rocks (Holt et al., 2008).

The recent work of Ojha et al. (2015) resolved the mystery which first arose when Mars Global Surveyor images showed the presence of sources of liquid water underneath Mars at shallow depths. These included gullies within the walls of some impact craters, pits at the south pole and two river valleys which showed features normally explained by groundwater seepage and runoff (Malin and Edgett, 2000). Some had advanced theories to explain these flows by other mechanisms, e.g. that sand movements or liquid CO_2 flow might account for it (Musselwhite et al., 2001) since the notion of liquid water on the Mars surface still aroused opposition and incredulity. The Mars Global Surveyor also produced considerable data supporting the notion that early Mars had persistent and long-lasting conditions which supported water flow on its surface, especially by its study of several valleys with tight sinuosity

[2] http://mars.nasa.gov/programmissions/overview/.

Table 1
Habitability factors from Mars Exploration Program Advisory Group (2006).

	Habitability factors
Water	• liquid water activity (a_w) • Past/future liquid (ice) inventories • Salinity, pH, and Eh of available water
Chemical environment	**Nutrients:** • C, H, N, O, P, S, essential metals, essential micronutrients • Fixed nitrogen • Availability/mineralogy **Toxin abundances and lethality:** • Heavy metals (e.g., Zn, Ni, Cu, Cr, As, Cd, etc., some essential, but toxic at high levels) • Globally distributed oxidizing soils
Energy for metabolism	**Solar** (surface and near-surface only) **Geochemical** (subsurface) • Oxidants • Reductants • Redox gradients
Conducive physical conditions	• Temperature • Extreme diurnal temperature fluctuations • Low pressure (Is there a low-pressure threshold for terrestrial anaerobes?) • Strong ultraviolet germicidal irradiation • Galactic cosmic radiation and solar particle events (long-term accumulated effects) • Solar UV-induced volatile oxidants, e.g., O_2^-, O^-, H_2O_2, O_3 • Climate/variability (geography, seasons, diurnal, and eventually, obliquity variations) • Substrate (soil processes, rock microenvironments, dust composition, shielding) • High CO_2 concentrations in the global atmosphere • Transport (aeolian, ground water flow, surface water, glacial)

and deep channeling and fans in some impact craters (Malin and Edgett, 2003). The duration of early "warmer and wetter Mars" is crucial to whether life was able to evolve there. Scientists are still divided between those who argue for short periods, perhaps with enough episodic volcanic activity to allow for liquid flow and surface water and those who think this period might have been as long as hundreds of millions of years, e.g. McKay and Davis (1991). Earth studies and modeling has led some researchers to advance the idea that an impact creating a hydrothermal system which can persist for just two million years (which would require a 130 km crater) would provide enough time for microbial life to evolve (Westall et al., 2013).

The implications of these exciting decades of Mars exploration for life were articulated in NASA's press releases announcing Ojha et al.'s discovery of flows of liquid water on the planet's surface. Michael Meyer, lead scientist of the Mars Exploration Program at NASA headquarters, noted "It seems that the more we study Mars, the more we learn how life could be supported and where there are resources to support life in the future".[3]

In January 2014, NASA announced that the Curiosity and Opportunity rovers now had the task of searching for signs of ancient Mars life, including several types of microorganisms, and for ancient water environments which may have been favorable to the emergence of life (Grotzinger, 2014a, 2014b). The Mars Exploration Program Analysis Group noted that a major milestone had been achieved: "Conclusive proof that liquid water existed for long periods on the ancient Martian surface. Significance: Dramatically increases the probability that life or proto-life could have developed on Mars during its early history, and perhaps did".[4] They also noted: "If life evolved there, conceivably it may still survive".[5]

Indications that our paradigm has indeed changed are rapidly emerging. For instance, a panel tasked with planetary protection met recently to update their inventory of "Special Regions on Mars" where terrestrial organisms might reproduce. New data from study of extremophile organisms on Earth has changed views on where on Mars terrestrial organisms might be viable and thus cause potential contamination interfering with the search for life. These are sites which the recent discoveries have shown are more favorable to finding either fossil or extant Mars life (Rummel et al., 2014). Calls have also emerged for a new life-detection mission, 40 years after the Viking lander experiments (Schulze-Makuch et al., 2015).

Some continue to contend that though the Viking life-detection experiments were conducted long before our modern understanding of Mars' history and environment, those experiments may have indeed found life. At the time they were declared inconclusive, though one test showed a positive result. One of the Viking objectives was to find organic molecules. This was finally achieved by Curiosity rover in 2014.[6] Recent reassessments of other Viking experiments, noting the discovery of perchlorate by the Phoenix lander, concluded that organics in the soil would have been destroyed by that salt producing the same chlorine byproducts which Viking discovered (Navarro-González et al., 2006). Interpretation of Viking data is still highly debated.

The other claim to finding fossil life and evidence of microbial activity in early Mars also remains controversial. A NASA/university group examined the only Mars meteorite which dates from the earliest geological eras, 3.5 billion years ago. They concluded that it contained evidence of fossil nanobacteria of non-terrestrial origin and of a type of magnetite only associated with special microorganisms on Earth (McKay et al., 1996). A 2009 reassessment by other NASA scientists, using more detailed analysis than was originally possible, concluded that the biogenic explanation for the magnetite is the most viable explanation (Jeffs, 2009).

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[3] https://www.nasa.gov/press-release/nasa-confirms-evidence-that-liquid-water-flows-on-today-s-mars.

[4] Mars Exploration Program Advisory Group, http://mepag.jpl.nasa.gov/topten.cfm?topten=1.

[5] http://mepag.jpl.nasa.gov/topten.cfm?topten=1 quoted in http://www.theatlantic.com/science/archive/2015/09/water-is-flowing-on-mars/407662/.

[6] http://news.sciencemag.org/chemistry/2015/03/mars-rover-finds-long-chain-organic-compounds.

The search for promising locations where Mars life might have arisen (and still persist) is very complicated, although previous and present Mars exploration has already identified quite a few locations worth examining. The severe cosmic radiation on Mars surface virtually precludes any life being possible there and even for meters underground. One team concluded viable dormant cells would have to be at least 7.5 m deep (Dartnell et al., 2007). This has difficult implications for the equipment needed to search for life. Table 1 shows some of the considerations that it is believed must be met for life on Mars.

Still, there are tantalizing clues which have emerged to lend some credibility that life might still exist (if it ever arose) on Mars. For example, methane was detected and confirmed in the Martian atmosphere in 2003–2004 (Mumma et al., 2009; Formisano et al., 2004). There are non-biogenic explanations which might account for methane release. In December 2014, Curiosity rover reported it had detected a spike of ten times the normal methane, suggesting episodic release (Webster, 2015). Further study and isotopic analysis will be required to see if this is a true sign of Mars life. There is also interest in whether the finding of formaldehyde is a sign of life or active geology (Peplow, 2005). Amongst a host of emerging locations which seem promising for a search for fossil or active life is the silica-rich location discovered by Spirit rover in 2007, suggestive of Earth's hot springs. Hydrothermal deposits, which on Earth are rich with microbial life, have been flagged as leading candidates for exploration (Allen et al., 2000).[7]

The "follow the water" campaign has yielded unexpected and exciting insights into our nearest planetary neighbor. We have a far greater understanding of Mars, though uncertainties and controversies abound. We have indeed entered into a new and exciting era of Mars research: the search for life. Though conditions might have been favorable to the emergence of life on Mars, that does not mean that it ever did. That uncertainty, and the potential significance of our search for life, promise that Mars exploration will continue to provide plenty of surprises and drama.

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