THE HABITABILITY OF THE PHOENIX LANDING SITE: AN EVALUATION OF MISSION RESULTS

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Introduction: The recent Phoenix mission landed in May 2008 in the Northern Plains of Mars and sampled soil and ground ice. A mission goal was to determine whether the landing site was a habitable zone, meaning capable of supporting living organisms with capabilities similar to terrestrial microbial life. According to MEPAG [1,2] the potential for habitability in a specific time and space encompasses three factors: (1) the presence of liquid water (P_{lw}), (2) the presence of a biologically available energy source (P_e), and (3) the presence of the chemical building blocks of life (e.g. C, H, N, O, P, S) in a biologically available form (P_{ch}). In addition to these factors, temperature and water activity must be high enough to support growth, and the environment must be benign and nontoxic. Since these factors must be simultaneously present, MEPAG [1] defined a Habitability Index, HI= 100 * P_{lw} P_e P_{ch} , which is the product of the probability represented by each of the three factors, and posited that a life detection mission could not be justified unless a previous mission had determined HI to have a combined probability greater than 50. Thus a quantitative evaluation of habitability is a precursor requirement for sending a mission to search for life. The Phoenix mission team evaluated the HI for the Phoenix landing site based on relevant observations from the mission [3]. This paper reviews those results and shows how HI for Phoenix compares with other previously visited landing sites.

Approach: Each of the above probabilities can further be decomposed into sub-elements or observables that combine for its evaluation. Each probability is computed using the formula $P_n=\Sigma F_{ni} W_i/\Sigma W_i$ (Eq. 1), which is the normalized sum of relevant factors, weighted relative to each other by the importance of each factor and/or the certainty associated with the observation. In equation 1, F_{ni} are the factors identified, and W_i are their weights. In all cases, the factors are evaluated qualitatively, assigned values of null, low, medium, medium-high or high. To evaluate Eq. 1, these qualitative measures are equated to numerical values 0, .25, 0.5, 0.75, and 1. Weights estimate the relative importance of each factor, or the uncertainty in the analysis of the factor, and are also in the range 0 to 1.

Liquid water probability, P_{lw}, is comprised of two main factors: F_o, observations (chemical or morphological) that suggest liquid water; and F_{th}, theoretical models that show ice melting is possible under recent climate conditions. Observations that suggest liquid water may have occurred include 1) heterogeneous subsurface ice morphology including the presence of possible segregated ice located in a polygon trough area as compared to ice cemented soil located in the polygon center; 2) carbonate minerals were observed by both the Thermal Evolved Gas Analysis (TEGA) and Wet Chemistry Laboratory (WCL) instruments; and 3) microscopic evidence shows possible chemical etching of soil particles.

Theoretical considerations for the presence of liquid water involve both a mechanism to emplace water at the landing site and climatic conditions that support stable or even transient liquid water. Snow was observed on Mars by the LIDAR instrument and SSI camera [4] and near surface ground ice is also an available water source. The Mars North Polar region (and the landing site) experiences periodic climate change associated with the variation in orbital parameters causing conditions that are far warmer than at present, and sufficient to cause surface melting of pure liquid water [5]. The observational and theoretical evidence for liquid water results in a combined value for P_{lw} of medium or 058.

The evaluation of P_e considers the presence of energy available to biological systems. At the surface, solar energy is available and is a dominant energy source. However, the presence of strong ultraviolet radiation may result in sterlization if metabolism is not active enough to overcome high rates of organic destruction. In the subsurface, below the photic zone, metabolism is only possible if chemistry supports oxidation reduction reactions (redox pairs) for chemoautotrophy. Perchlorate salt was identified in the soil by the WCL, probably in the form of $MgClO_4$[6]. The reduction potential of perchlorate and chlorate (1.287V; 1.03V) makes these compounds ideal electron acceptors for microbial metabolism and they are utilized as an energy source by numerous species of microbes [7]. Perchlorate reducing bacteria grow by the oxidation of organic carbon or inorganic electron donors (H_2, H_2S, or Fe_2+) coupled to the reduction of perchlorate. They grow under a wide range of environmental conditions including in Antarctic soils, and have a broad range of metabolic capabilities including (of relevance to Mars) the oxidation of soluble and insoluble ferrous iron. Since both Sunlight and chemical energy are available in the same zone where liquid water can occur, P_e is assigned a high value (P_e=1).

Factors considered for P_{ch} , the probability of presence of chemical conditions conducive to life, include presence of soluble ions of biogenic elements (CHNOPS), presence of other elements known to support metabolism, and the presence of nontoxic chemical conditions. The presence of carbonate(s) and the weakly alkaline pH means that, in addition to the atmospheric reservoirs of C (as CO_2 and CO), there is an abundant source of readily available C in the soil. H is available from H_2O. There is no information on fixed nitrogen on Mars. Although some terrestrial organisms are capable of converting atmospheric N_2 to nitrate, it is energy-intensive and biochemically complex so nitrates in the soil would be a very important nutrient source. WCL ISE for nitrate detection was masked by its response to perchlorate ions. However, in Atacama Chile, where perchlorate forms in the driest terrestrial deserts, nitrate also occurs in uncommonly high abundances. The aggressive oxidants in the martian atmosphere may produce nitric acid which then can be scavenged by the soil to produce nitrates. Hence, the occurrence of perchlorates is consistent with nitrates in the soil. In addition to sources in the atmosphere (O_2, O_3, H_2O_2) and various photochemical oxidizing non-molecular forms (OH radical, O*, O-, etc.), the perchlorate salts provide a storehouse of relatively readily available oxidizing power. No measurements of P content are available for Phoenix samples but phosphorus-containing minerals are abundant in all MER samples, including strong enrichments in Ca phosphates in some suites of materials in the Columbia Hills. Martian meteorites contain phosphates extractable using mildly acidic solutions (pH 5 or lower). P is inferred to be as abundant in martian soils as in terrestrial soils, although the alkaline pH implies from limited solubility of most plausible minerals that P will be present at trace but sufficient quantities for metabolism. Phoenix results imply that sulfate is available in the form of anhydrite [7] has been identified in many locations on Mars. Because of global dust storms, it is anticipated that some fraction of globalized dustcontaining S is present in the topmost polar soils at least. All sulfates of major cations except $CaSO_4$ are highly soluble, and should provide trace quantities which are as bioavailable as most terrestrial non-oceanic environments. Based on these considerations, all factors for the biogenic elements are evaluated as high except N which is evaluated medium, resulting in a P_{ch}=0.92 (high).

Finally, a probability factor is assigned for the presence of a benign and nontoxic environment (P_b). The measured pH of 7.8 is only slightly alkaline, comparable to most semiarid soils, and ideal for a broad range of organisms. While salts are identified in the soil, they are not at high enough concentration to cause inhibition of growth due to low water activity. WCL measured ions of Potassium, Calcium, and Magnesium, recognized nutrients for microbial growth, that are in the normal range for terrestrial soils. Based on these considerations, P_b is assigned a high value.

Results: An evaluation of Equation 1 with values assigned from the data shows that the HI for the Phoenix site is higher than for any other landing site previously visited. Figure 1 shows how the landing sites compare for both the MEPAG HI and ours which includes an additional probability associated to environmental conditions, therefor resulting in a lower total probability. The graph also shows the formal error bars for the calculation. Since many of the factors in the calculation are uncertain, the absolute value of the HI is similarly uncertain, but the general conclusion is that the Phoenix landing site is the most habitable of all sites visited on Mars.

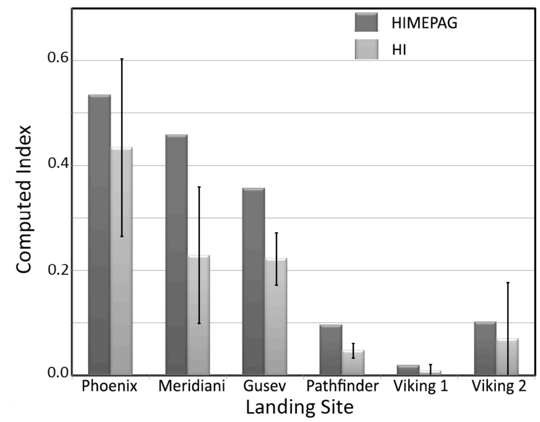

Figure 1. Habitability index evaluated for Phoenix and compared with other landing sites.

In summary, Phoenix landed at a location on Mars with a higher potential for detecting life than any site previously visited and sampled icy material that periodically may be capable of sustaining modern biological activity. The payload selected provided key information about the potential habitability of this environment and the data suggest habitable conditions have occurred in modern times.

References:

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